Byers Gill Solar
EN010139

Technical Note

8.18 Little Stainton Beck Hydraulic Modelling

1. Introduction

1.1. Background

1.1.1. Wallingford HydroSolutions Ltd (WHS) has been commissioned on behalf of RWE (the applicant) to undertake 2D-only modelling of the Little Stainton Beck, which is located to the south of Great Stainton and approximately 7km north east of Darlington (E: 434012, N: 520965). The purpose of the hydraulic modelling is to establish the flood risk to solar panel area D02, part of the proposed Byers Gill Solar Farm (The Proposed Development). The Environment Agency's (EA) fluvial flood map was deemed to be unrepresentative of the flood risk posed by the Little Stainton Beck.

1.1.2. The EA have requested that detailed hydraulic modelling is therefore undertaken to quantify this risk. A meeting was held with the EA on 12 June 2024 to agree the scope of this modelling exercise. It was agreed that a 2D-only model would be suitable alongside requirements for the model build, design return periods and sensitivity testing.

1.2. Methodology

1.2.1. A 2D-only model of the Little Stainton Beck has been developed. The modelled reach includes approximately 1.7km of watercourse, the focus of which is on that in the vicinity of Panel Area D02, shown in Figure 1. The hydraulic model has been produced using TUFLOW software and flows into the model have been informed by a hydrological assessment of key watercourses, provided as an FEH calculation record, found in Appendix A of this technical note. Ground levels and channel levels are based on LiDAR data [1], flown in 2022.

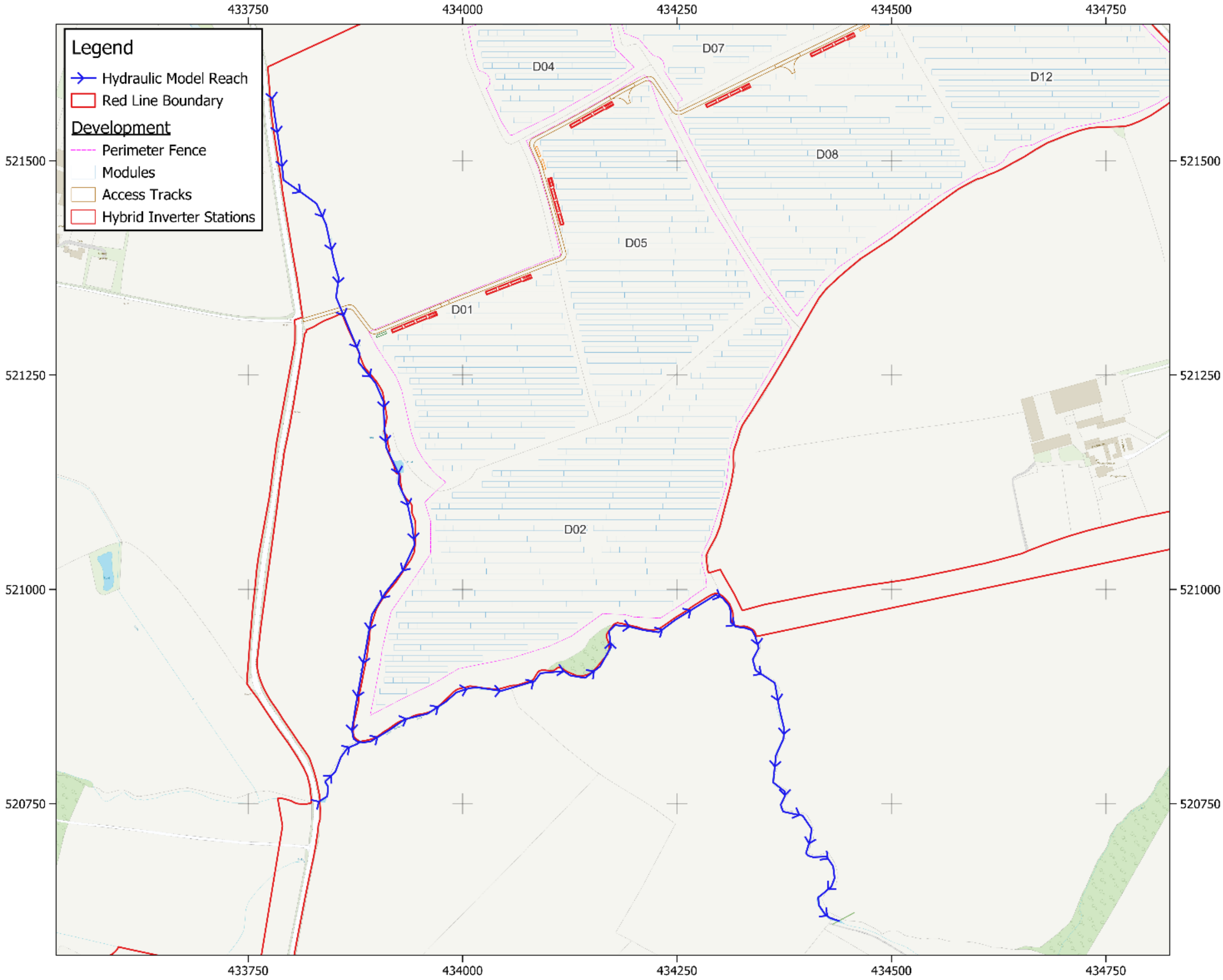


Figure 1 – Site Location and Planned Development.

2. Model Hydrology

2.1. Catchments

2.1.1. To inform flows into the hydraulic model, four hydrological assessments have been undertaken, for full details in the form of an FEH calculation record, see Appendix A. The four assessed catchments consist of two direct inflows and two lateral inflows. This inflow configuration was chosen because of the small size of the river channel, where larger inflows at the top of the model may cause more spillages into the upstream floodplain before reaching the area of interest. Therefore, flows have been distributed more evenly throughout the model.

2.1.2. These catchments can be seen below in Figure 2. The overall size of the catchment is 4.76km^2. The downstream-most point was chosen because it was 300m downstream of the solar panel area D02, ensuring that the downstream model boundary does not interact with the area of interest (D02).

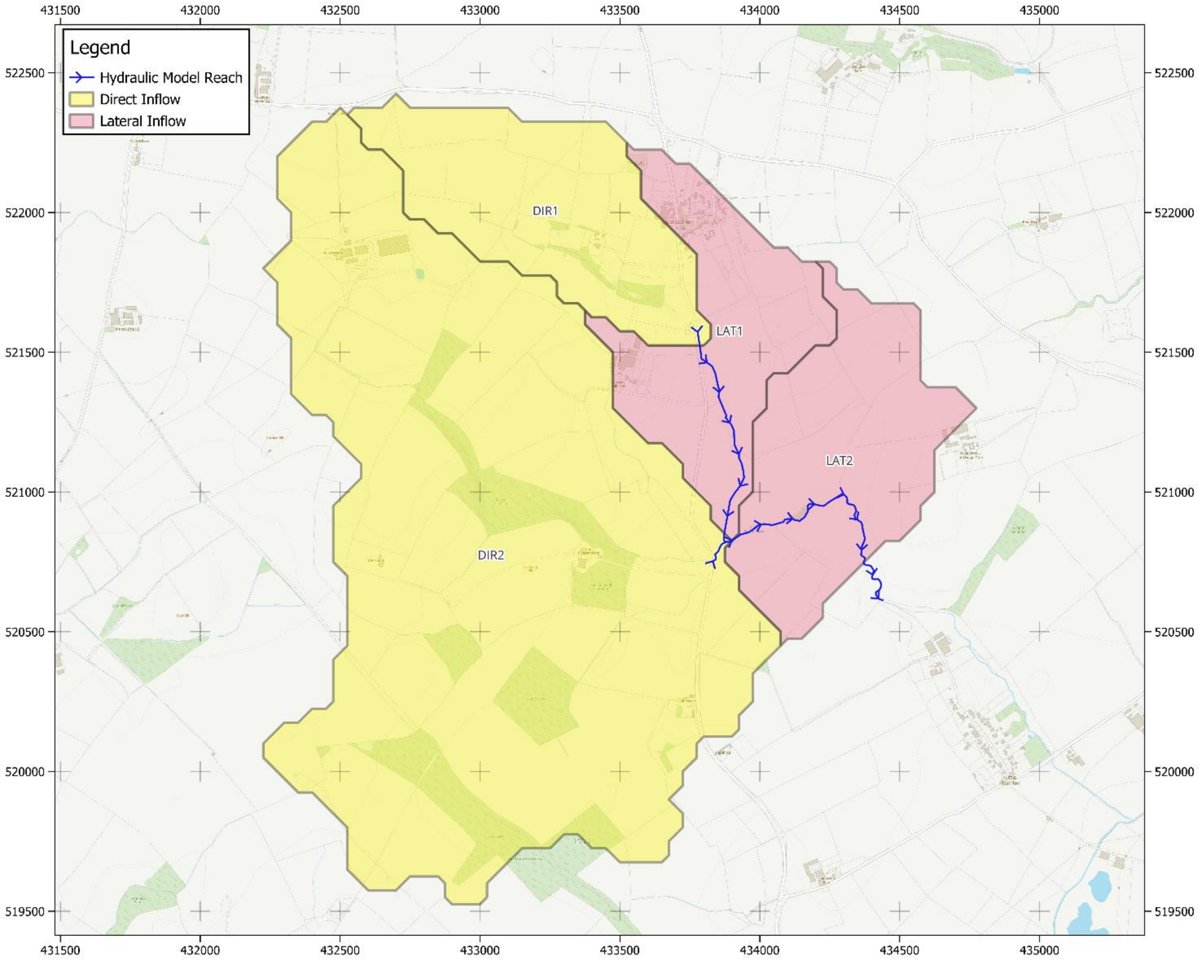


Figure 2 – Hydrologically assessed catchments

2.2. Peak Flows

2.2.1. The hydrology for both inflows were assessed by extracting the relevant catchment descriptors from the FEH webservice and then applying the FEH methods. The FEH methods, in this case, include the statistical method applied in WINFAP-FEH (v5) and the rainfall-runoff method applied in ReFH2.3. The final peak flow estimates are presented in Table 2-1 below.

2.2.2. Climate change allowances have also been applied based on EA peak river flow guidance for the Tees Management Catchment [2]. As per the NPPF [3], this development is considered 'Essential Infrastructure' and is located within flood zone 3, because of this, the development should be assessed using the higher central climate change allowance for the 2080s epoch. As a sensitivity test, the upper end allowance has also been calculated. The climate change allowances are therefore 40% (higher) and 61% (upper).

Table 2-1 Peak Flows Extracted for the four Hydrology Assessments.

Annual Exceedance Probability (AEP)	DIR1 peak flow (m^3/s)	DIR2 peak flow (m^3/s)	LAT1 peak flow (m^3/s)	LAT2 peak flow (m^3/s)
3.3%	0.358	1.365	0.311	0.386
1.0%	0.479	1.776	0.416	0.517
1.0%+40CC	0.671	2.486	0.582	0.724
1.0%+61CC	0.771	2.859	0.670	0.832
0.1%	0.805	2.781	0.699	0.869

3. Model Development

3.1. Software

3.1.1. TUFLOW's Latest 2023 release (2023-03-AB) was used to develop the 2D-only model, which was run on a GPU using the HPC solver.

3.2. Model Extent

3.2.1. The 2D domain covers a 0.52km^2 area, the domain was defined by hand, with the goal of minimally impacting the solar panel area (D02). To ensure this, the upstream model boundary is located downstream of any significant structures, beginning in river channels with embankments clearly defined by LiDAR. The downstream-most point of the model extent ensured that it did not impact the flow regime at D02. Additionally, the boundary was expanded to capture all out of bank flows, ensuring that there was no 'glasswalling' present in the model.

3.3. Representation of the River Channel Geometry

3.3.1. DTM was used to represent both the river channel and the floodplain. The DTM has a 1m resolution and was flown in 2022. The LiDAR data was downloaded from the DEFRA LiDAR portal [1]. For the purposes of this assessment, the DTM is detailed enough to define the key watercourses and embankments.

3.4. Structures

3.4.1. No structures of significance have been identified within the modelled reach. The upstream boundaries were located such that they are suitably offset from the area of interest but also just downstream of notable structures so as not to introduce any uncertainty with their representation in a 2D only model.

3.5. Boundary Conditions

3.5.1. Three boundary condition types were used in the modelling:

- QT (Flow vs Time) boundary to represent the inflow hydrographs from the lumped estimates upstream (see section 2)
- SA (Flow vs Time; Over an Area) boundary which slowly fills the channel, evenly distributed throughout all pixels in the channel.
- HQ (Flow vs Head) boundary used to allow flow out of the model.

3.5.2. For the downstream boundary, the average slope of the channel was calculated from the LiDAR data, and applied across the HQ boundary, this gradient is 0.045m/m. Figure 3 below shows the model domain and the location of the boundary conditions.

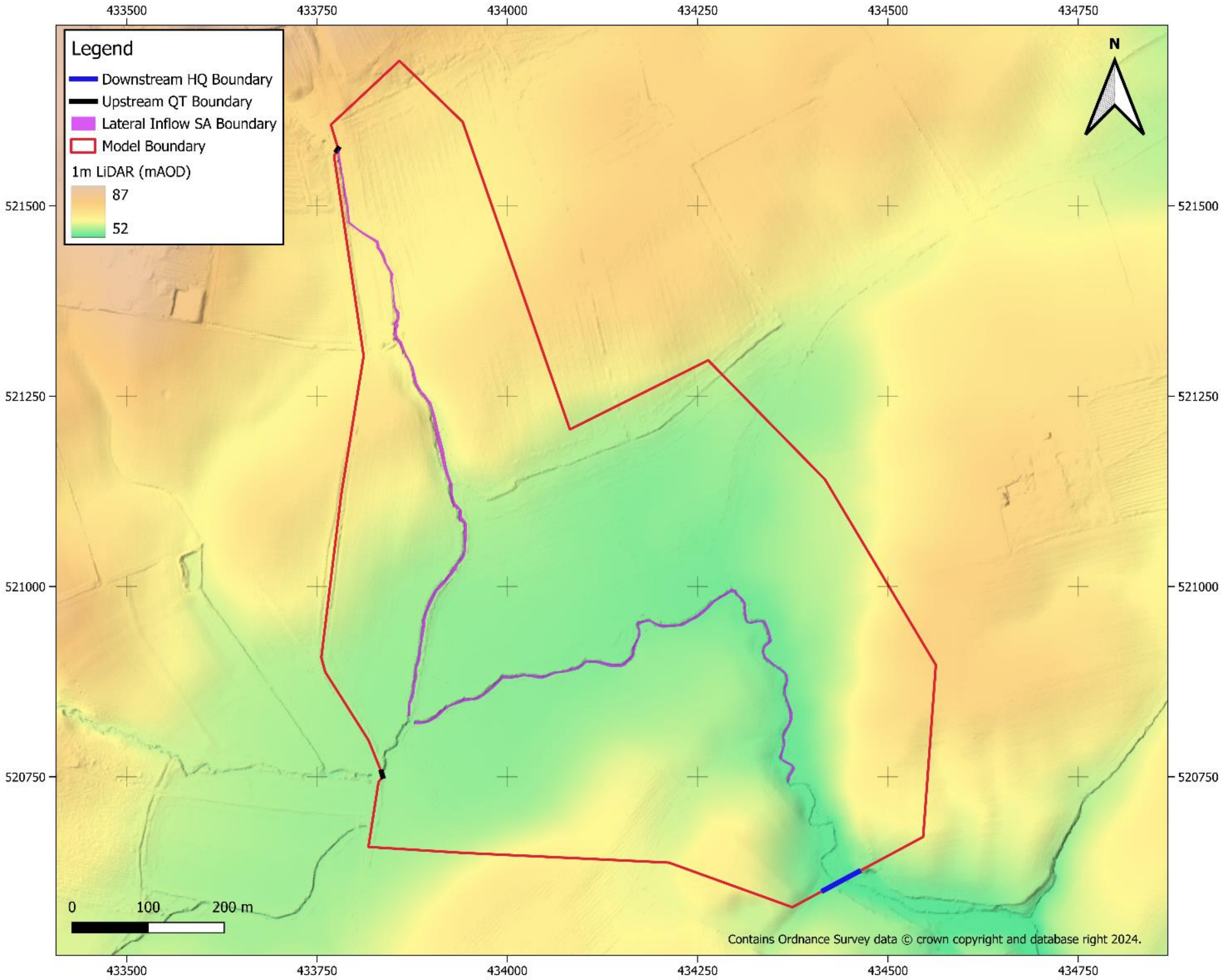


Figure 3 – Model domain and boundary conditions

3.6. Grid Size and Orientation

3.6.1. The model grid size has been set to 2m and the orientation of the grid is defined by a location line.

3.7. Initial Water Levels

3.7.1. The LiDAR picks up water levels in the watercourse at the time of the survey, this is considered sufficient representation and initial water levels have not been applied.

3.8. DTM Modifications

3.8.1. The channel is represented well in the LiDAR, however there are some instances where it is interrupted briefly by higher ground (all approximately less than 5m in length). This could be due to the uncertainty of the LiDAR data in areas with dense tree covering or potentially the presence of short unmapped crossings over the watercourse. To ensure these do not act as obstructions to flow within the watercourse, the most prominent ones have been filtered out.

3.8.2. 2d_zsh shapefiles have been implemented at six locations to 'flatten' small channel breaks that can be seen in the LiDAR. The shapefiles interpolate between the nearest upstream and downstream bed levels of the identifiable channel, meaning there will be a smooth gradient within that section. Figure 4 illustrates the location of the six 2d_zsh files.

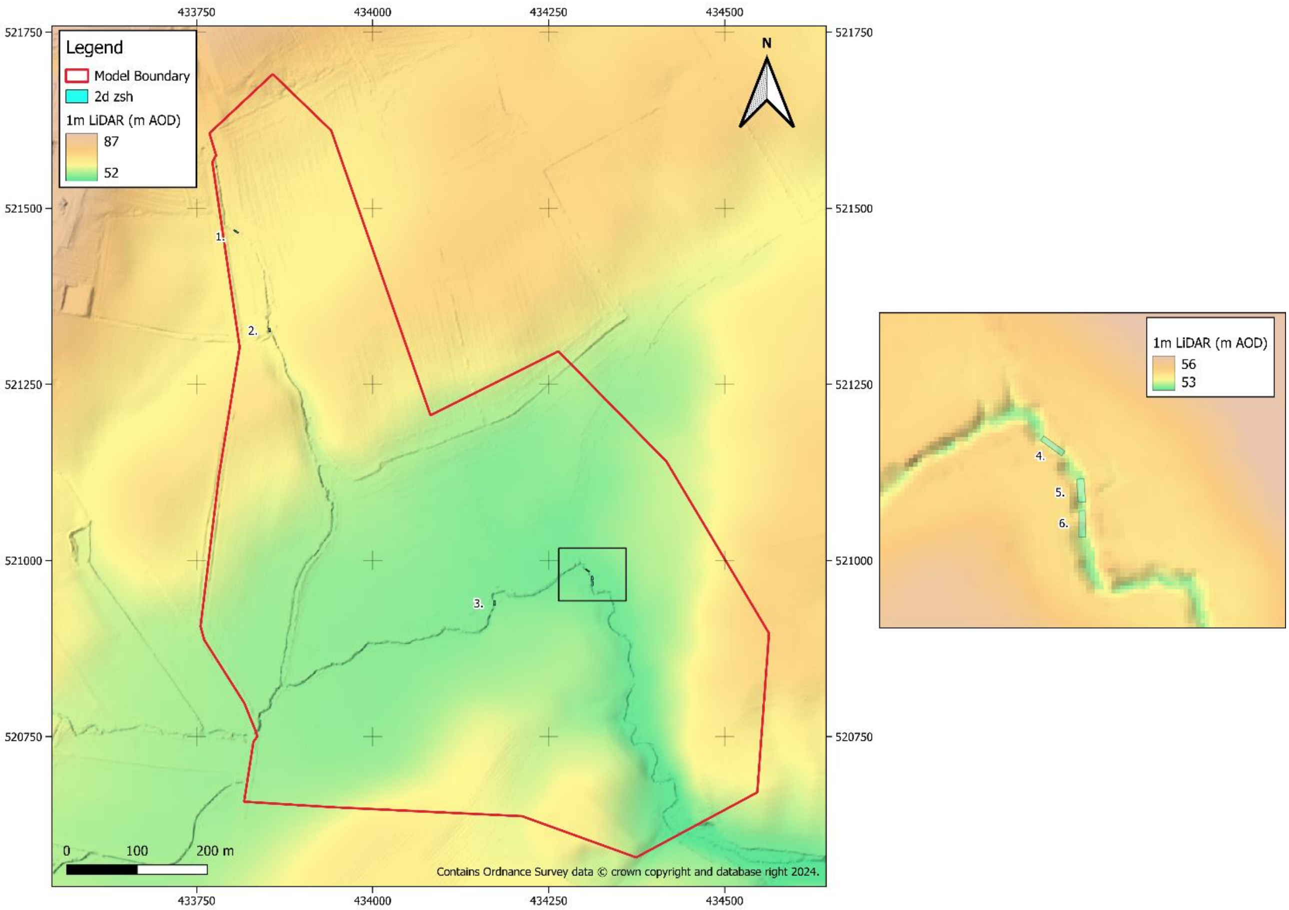


Figure 4 – 2D Z shape locations

3.8.3. OS mapping indicates there is a pond that the river channel flows through, however the LiDAR data has been deemed sufficient to represent the level of the surface of the pond, and so no adjustments have been made to the ground level.

3.9. Surface Roughness

3.9.1. The method used to represent hydraulic roughness in the floodplain is via the use of the Manning's N coefficient. The prominent land-use types in the model domain have been identified using a mixture of OS and satellite mapping. These land use types are then assigned a roughness value in the 2D Materials File. The Manning's N values used are displayed in Table 3-1. Variable roughness has been applied to the natural land, with increased roughness at lower flows in line with figure 17.7 in the CIRIA SUDS manual [4].

Table 3-1 Manning's N values

Land use type	Manning's N value
Fields	**0.035**
Woodland	**0.100**
Roads	**0.020**
Water bodies	**0.025**

4. Model Results

4.1. Summary of Design Runs

4.1.1. The hydraulic model has been run for the following events:

- 3.3% AEP event
- 1.0% AEP event
- 1.0% AEP event + higher climate change estimate (40%)
- 0.1% AEP event

4.1.2. The climate change allowance has been applied in line with the EA guidance on peak river flow allowances for Essential Infrastructure in the Tees Management Catchment [2]. As per the NPPF [3], this development is considered 'Essential Infrastructure' the development should be assessed using the higher central climate change allowance for the 2080s epoch. The upper end allowance has also been run as detailed in section 5.

4.1.3. The hydraulic model has been run for each of the above events to obtain baseline results. The 3.3% AEP event has not been presented in this technical note.

4.2. Baseline Scenario

4.2.1. Figure 5 below shows the modelled maximum depth during the 1.0% AEP model run. As can be seen, the model shows the water flowing out of bank at several locations along the Little Stainton Beck, flowing through the fields, across the proposed solar area and then rejoining the channel before the it turns south. This means that a section of the solar panel area is inundated. The maximum depth adjacent to a solar PV module during the 1.0% AEP event is 0.48m. This area of flooding is located to the south east of the panel area, near to where the overland flow rejoins the watercourse. Elsewhere along the southern boundary of the panel area modelled flood depths are significantly lower and below 0.50m.

4.2.2. Figure 6 and Figure 7 illustrate the maximum depth of the 1.0%+hcCC AEP and 0.1% AEP events, respectively. Both of these events show similar extents to the 1.0% AEP event, with the maximum flooded depth within these boundaries being 0.53m and 0.54m. Again, excluding this southeastern most corner flood depths in the panel area are below 0.50m.

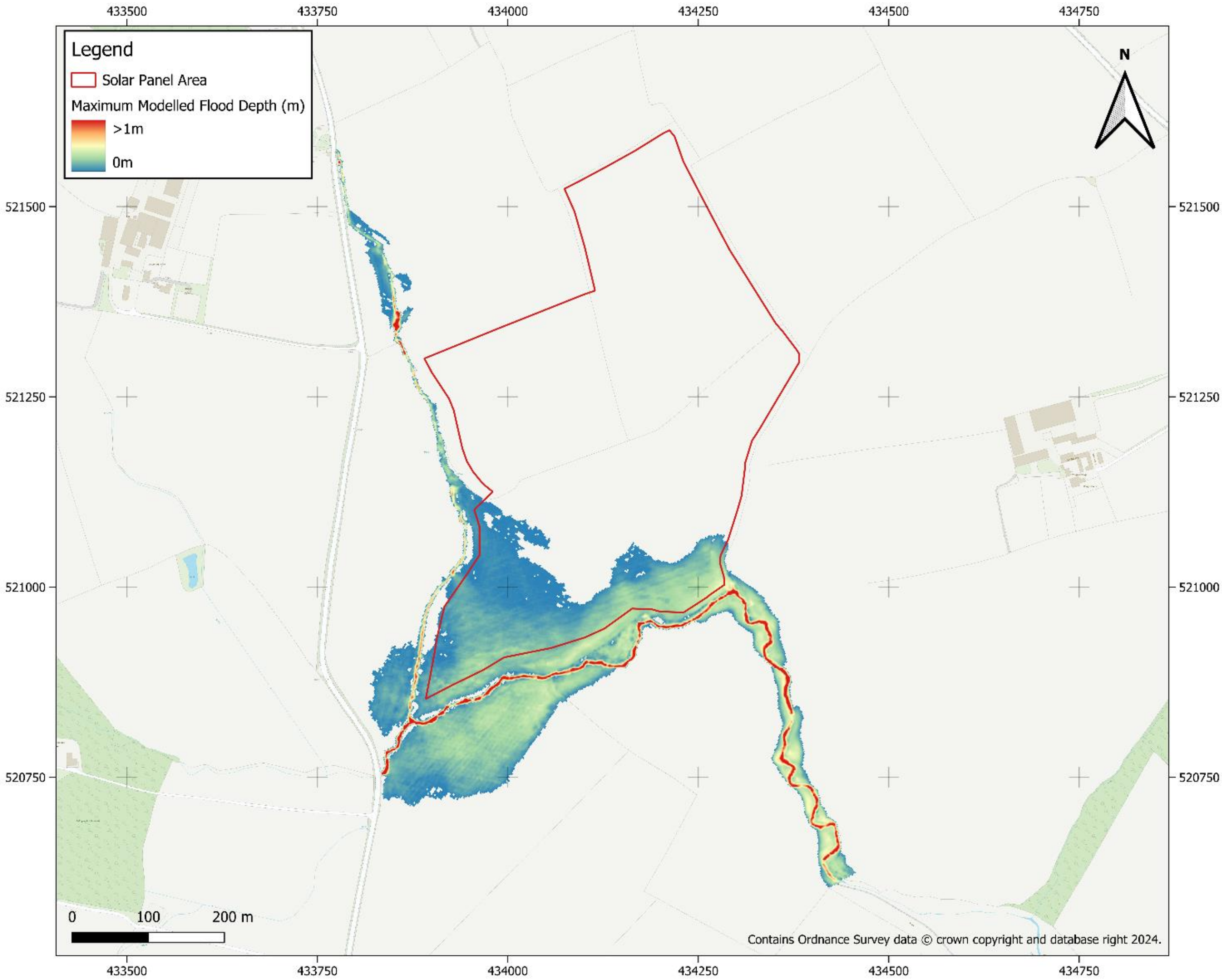


Figure 5 – Baseline Model Results – 1.0% AEP

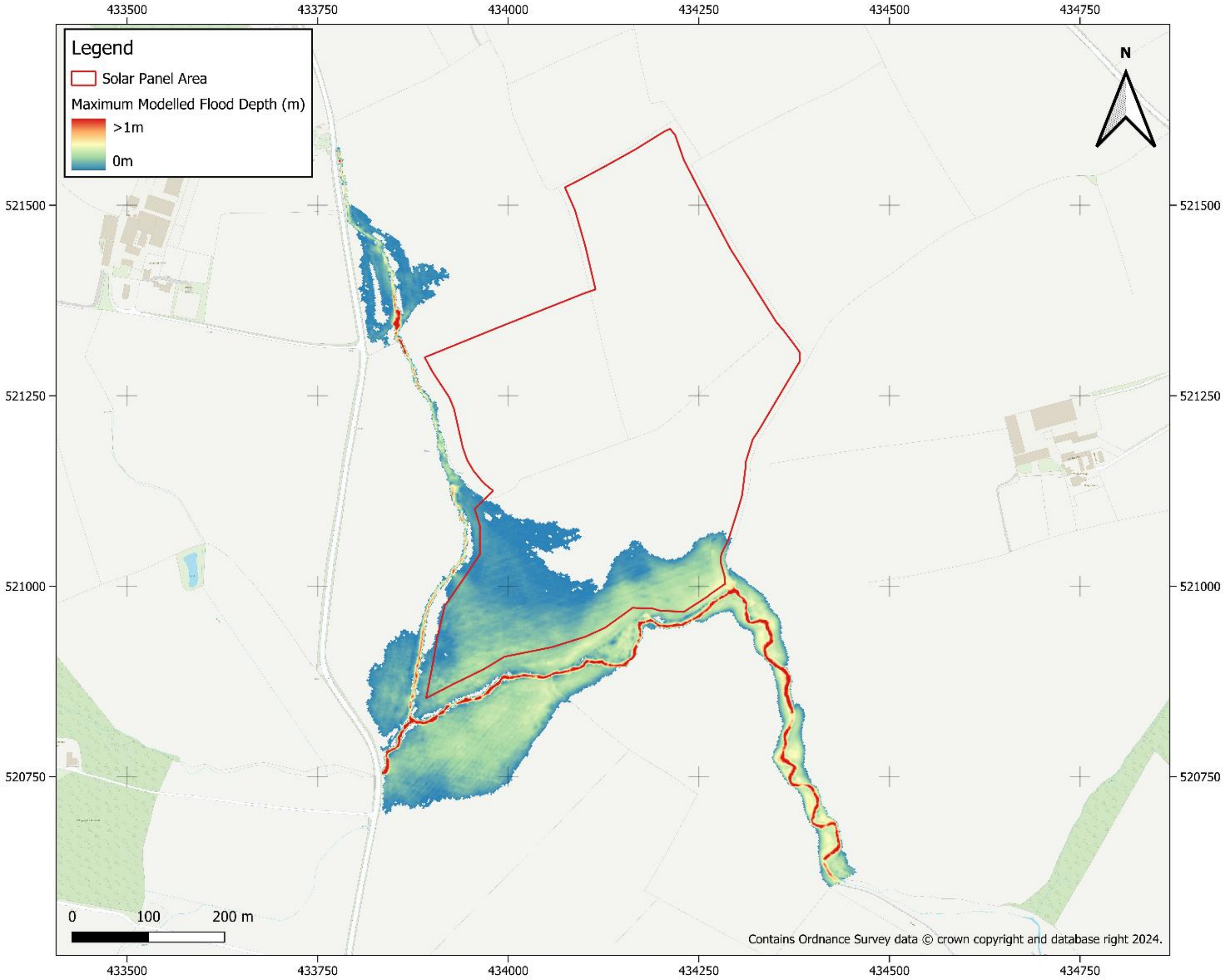


Figure 6 – Baseline Model Results 1.0% AEP + higher central CC

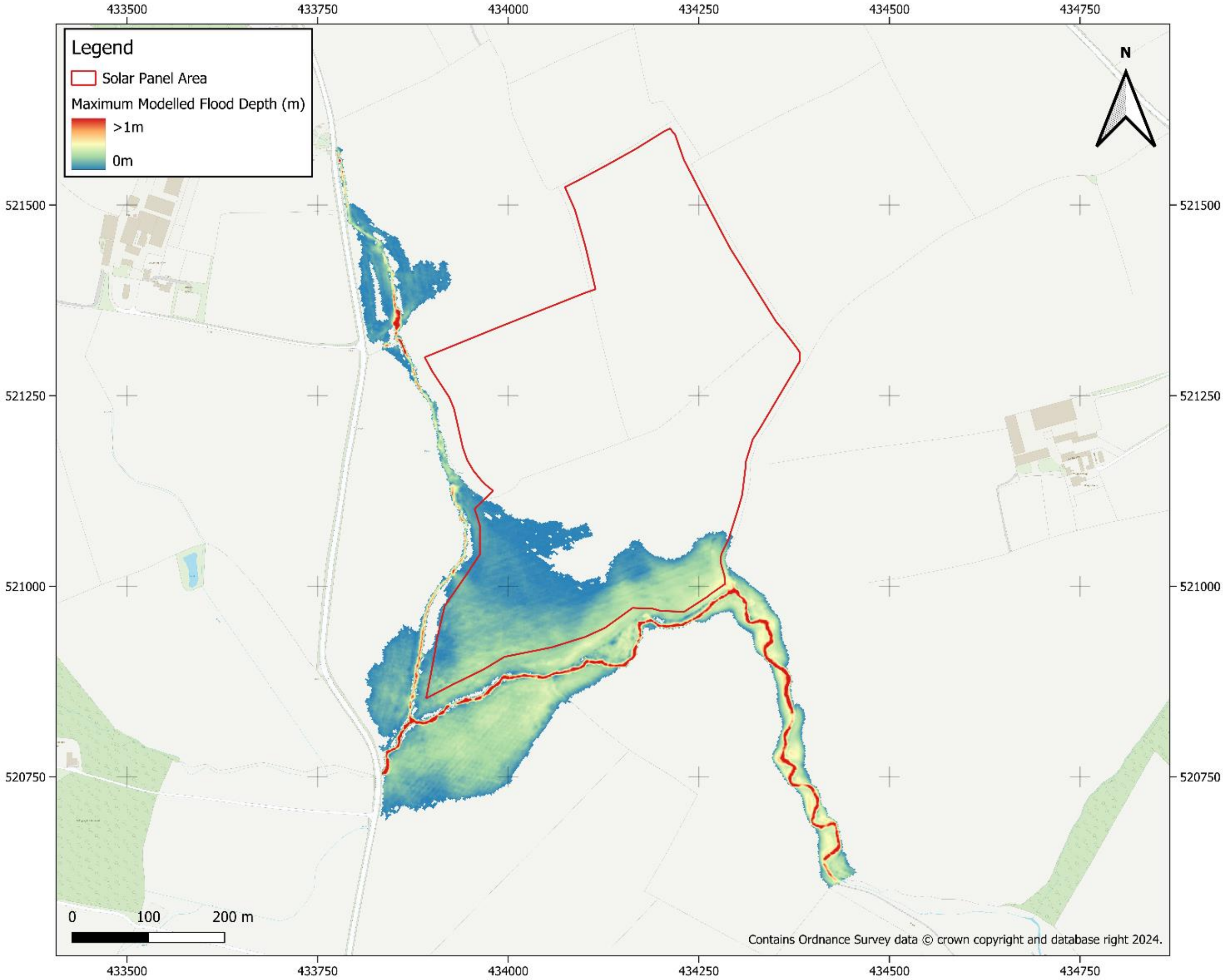


Figure 7 - Baseline model results 0.1% AEP

4.3. Post-development

4.3.1. Post-development modelling was completed by increasing the roughness value within the area of solar panels to reflect the potential increases caused by the panel legs. This was applied to the entire area within the fence line rather than the individual modules themselves. The roughness in this area was increased from 0.035 to 0.1. This was chosen as a conservative estimate, which typically is used to represent woodlands.

4.3.2. The post-development model runs for the 1.0%, 1.0% +hcCC and 0.1% AEP events are presented in Figure 8 below. The post-development flooding is predicted to spill out of the channel, across the solar panel area and back into the channel as it turns to the south. The maximum flood depth within the solar panel area during each of these events is 0.48m, 0.53m and 0.54m respectively. The impact this has on the design of the Proposed Development and requirement for freeboard has been addressed in ES Appendix 10.1 Flood Risk Assessment and Drainage Strategy (Document Reference 6.4.10.1).

4.3.3. The extents for the post-development scenario are not significantly different to the baseline conditions, this can be seen in the depth change plots, illustrated in Figure 9. This shows that the flood extent is negligibly impacted and some minor increases in flood depth in the southeastern corner of the field. The maximum increase in flooded depth seen is 0.043m, 0.041m, and 0.050m, respectively for the design events. This is largely isolated to the field within the Order Limits. The exception being a small area just outside of the Order Limits, within the watercourse itself and the right bank floodplain associated with an increase just above 0.010m. The panels therefore have a negligible impact on flood risk downstream.

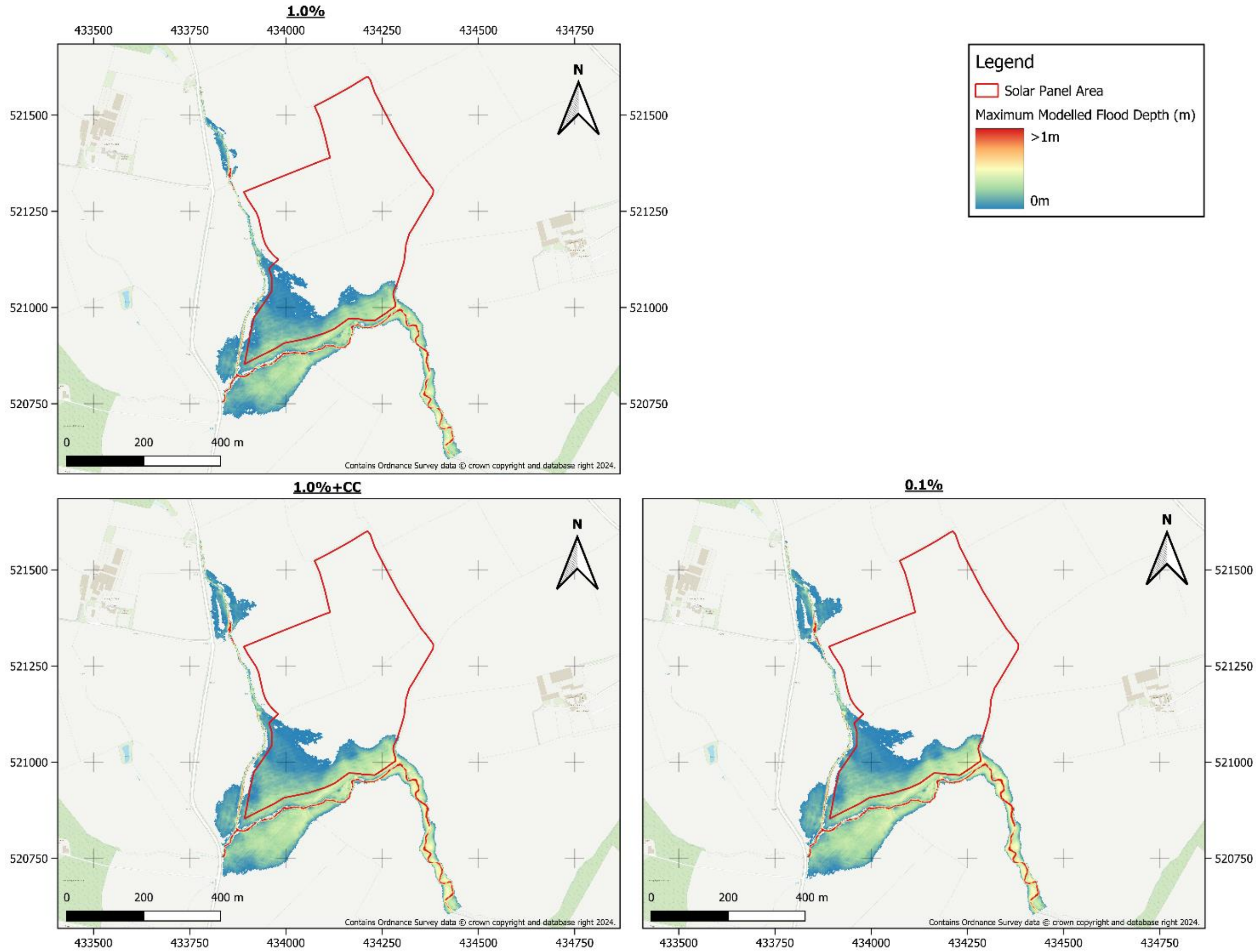


Figure 8 – Post-development model results. 1.0%, 1.0% +higher central CC and 0.1% AEP

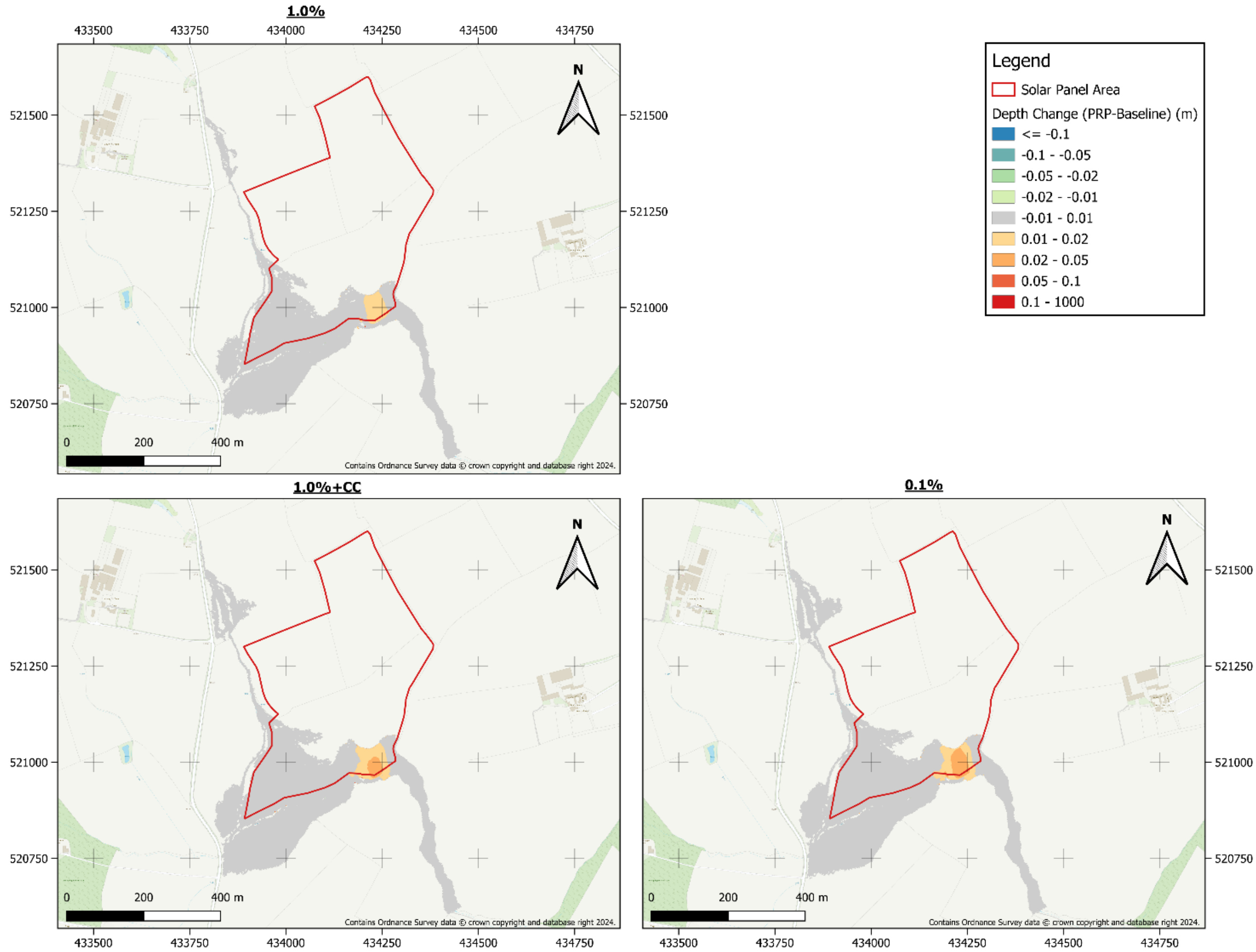


Figure 9 – Post-development depth change plots. 1.0%, 1.0% +higher central CC and 0.1% AEP

5. Sensitivity Analysis

5.1.1. Sensitivity analyses have been carried out on the baseline 1.0% AEP fluvial event on the following parameters:

- Manning's N: Roughness coefficients for channels and floodplains have been increased and decreased by +/- 20% respectively.
- Flow increase: The sensitivity of the model to changes in river flow has been assessed by comparing modelled flood depths during the 1.0% AEP event and 1.0% AEP event plus climate change (both for the higher and upper scenarios).
- Downstream boundary: The downstream boundary gradient has been modified by +/- 20%.

5.1.2. The results of the sensitivity analysis have been assessed at key points within the model domain and the sensitivity sample point locations are shown in Figure 10.

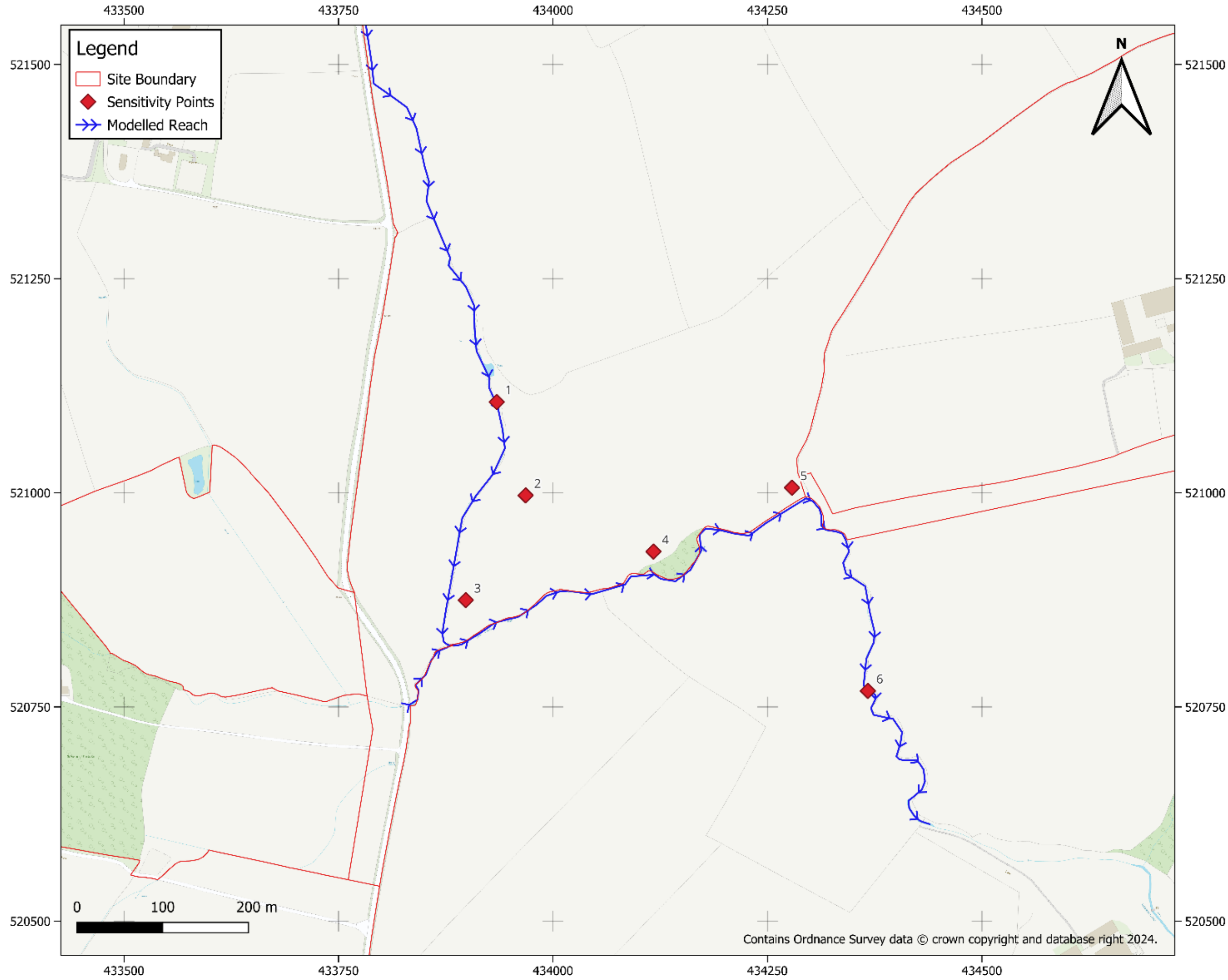


Figure 10 – Sensitivity point locations

5.2. Manning's N

5.2.1. The results of the sensitivity analysis are displayed in Table 5-1 below. The general pattern which can be seen is that increasing Manning's N increased the modelled depth, whilst a decreased Manning's N decreased the modelled depth, this is an expected outcome. The model is deemed to be acceptably sensitive to changes in Manning's N.

Table 5-1 Manning's n sensitivity analysis

Sensitivity Point	1% Baseline Depth (m)	SEN (N+) (m)	Difference (m)	SEN (N-) (m)	Difference (m)
1	0.214	0.223	0.009	0.203	-0.011
2	0.040	0.045	0.005	0.035	-0.005
3	0.156	0.174	0.018	0.134	-0.022
4	0.374	0.387	0.013	0.355	-0.019
5	0.456	0.471	0.015	0.438	-0.018
6	1.124	1.139	0.015	1.106	-0.018

5.3. River Flow

5.3.1. The results of the flow sensitivity analysis are displayed in Table 5-2 below. Modelled water depths increase when increased flows are inputted to the model. The increases seen are within the expected range.

Table 5-2 Rainfall sensitivity analysis

Sensitivity Point	1% Baseline Depth (m)	1% AEP + 40% CC Depth (m)	Difference (m)	1% AEP + 61% CC Depth (m)	Difference (m)
1	0.214	0.267	0.053	0.286	0.072
2	0.040	0.072	0.032	0.087	0.047
3	0.156	0.192	0.036	0.205	0.049
4	0.374	0.408	0.034	0.421	0.047
5	0.456	0.507	0.051	0.526	0.070
6	1.124	1.177	0.053	1.198	0.074

5.4. Downstream Boundary

5.4.1. The results of the downstream boundary sensitivity analysis can be seen in Table 5-3 below. As can be seen, increasing/decreasing the HQ boundary gradient does not alter the modelled depth at any of the sensitivity points, this is likely due to the distance of the boundary to the points, indicating the boundary is sufficiently far away from the area of interest.

Table 5-3 Downstream boundary sensitivity analysis

Sensitivity Point	1% Baseline Depth (m)	1% AEP HQ+ Depth (m)	Difference (m)	1% AEP HQ- Depth (m)	Difference (m)
1	0.214	0.214	0.000	0.214	0.000
2	0.040	0.040	0.000	0.040	0.000
3	0.156	0.156	0.000	0.156	0.000
4	0.374	0.374	0.000	0.374	0.000
5	0.456	0.456	0.000	0.456	0.000
6	1.124	1.124	0.000	1.124	0.000

6. Model Stability and Limitations

6.1. 2D Model Stability and Limitations

6.1.1. With the HPC solver, one of the main indicators of model stability is the time step selected by TuFLOW. This has been reviewed and plotted in Figure 11.

6.1.2. Ideally, the time step should not fall below one-tenth of the timestep that would have been used with the classic solver. For this model, a timestep of between 1.0 and 0.4 would have been selected for a grid resolution of 2m, hence the HPC timestep should not fall below 0.1 and 0.04 seconds. The plot of the evolution of the 2D timestep (dtStar) indicates that the timestep does not drop below the 0.1 for the duration of the model run.

6.1.3. In addition to the 2D timestep, there are three control numbers which must be satisfied.

- A Nu value of 1.0 or greater may indicate that the velocity is unusually high, or the cell size is too small for the modelled velocity.
- A Nc value of 1.0 or higher can be caused by large depths in relation to cell size.
- A Nd value of 0.3 or higher, might suggest that there is poor boundary setup, or insufficient SX cells linked to a 1D structure, or the cell size is too small.

6.1.4. Figure 11 indicates that the Nu control number is satisfied. However, both the Nc and Nd values reach their recommended thresholds for at least part of the model run. The exceedance of both parameters is likely due to the depth of the channel, where the water depth is greater than 1.5m for much of the simulation due to this being a 2D only model.

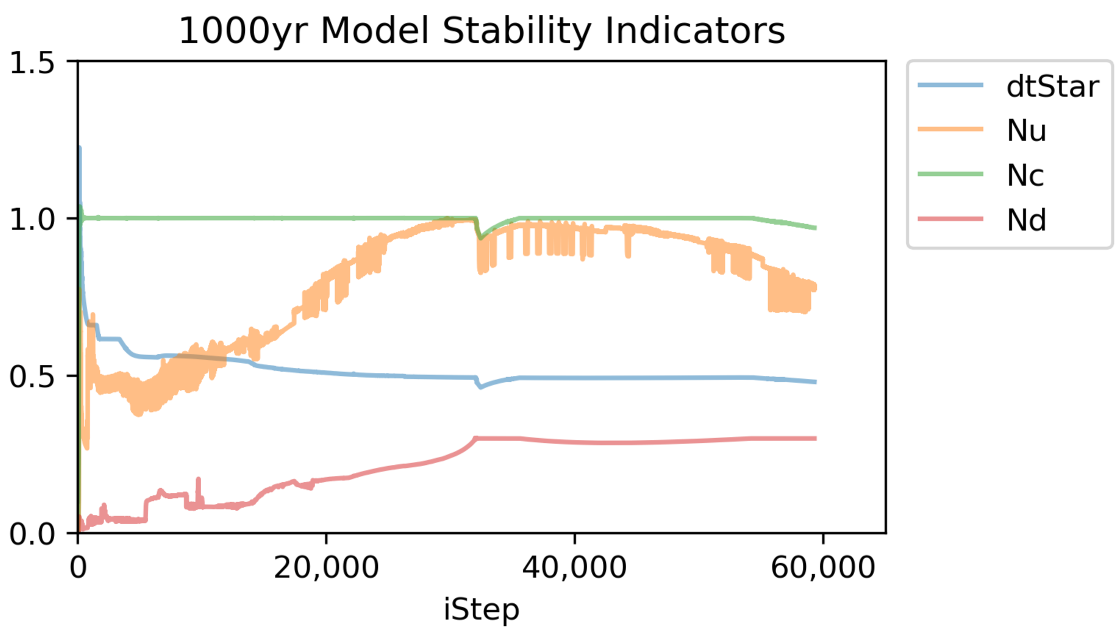


Figure 11 – Model stability indicators

6.2. Checks and Warning Messages

6.2.1. Check and Warning Messages are present in TUFLOW log file upon completion of the model runs for the 0.1% AEP event, these are summarised in Table 6-1. This warning type has been reviewed and is considered to be acceptable, because the warning relates to the high manning's n for the fields at low depths.

Table 6-1 – TUFLOW check and warning messages

ID	Count	Comment
Warning 2583	1	Material ID contains a manning's n value (0.400) greater than Wu n limit (0.100) - n value will be limited in Wu formulation.

7. Conclusions

7.1.1. This report details the methodology used to produce the 2D-only hydraulic model of the Little Stainton Beck. The hydraulic modelling was required to confirm flood risk to an area of proposed solar panels as part of the Byers Gill solar farm. The following bullet points summarise the results and conclusions of the report.

- The hydraulic model has been run for the 1.0% AEP, 1.0% AEP plus higher climate change allowance and the 0.1% AEP events, all of which showed flooding within part of the solar panel area.
- Post-development model runs were then completed, showing the development did not cause new areas of flooding, with only minor detriment occurring largely within the solar panel area and a small portion within the watercourse itself adjacent to the panel area.
- The maximum flood depth adjacent to a solar PV module during the 0.1% AEP, post-development scenario is just under 0.55m.
- A sensitivity analysis completed on the baseline hydraulic model for manning's n values, downstream boundary and flows indicate that the model is responding as expected to changes in these parameters and to a reasonable extent. Therefore, the model is deemed suitable to inform flood risk within the site boundary.
- A review of the model stability and checks and warning messages indicates that the model is stable and suitable to inform flood risk.

References

[1] DEFRA, “DEFRA Survey Data Download,” 2024. [Online]. Available: https://environment.data.gov.uk/survey. [Accessed 29 07 2024].

[2] DEFRA, “Peak River Flow Climate Change Allowances,” 2024. [Online]. Available: https://environment.data.gov.uk/hydrology/climate-change-allowances/river-flow. [Accessed 27 08 2024].

[3] Ministry of Housing, Communities and Local Government, “National Planning Policy Framework,” 2021.

[4] CIRIA, The SuDS Manual C753, 2015.

Appendix A
LIT 65087 Flood Estimation Report Little Stainton Beck

Flood Estimation Report Template

Template: LIT 65087	Published: 29/12/2022

Audience: Environment Agency

Description: This report template is a supporting document to the Environment Agency's Flood Estimation Guidelines (LIT 11832). It provides a record of the hydrological context, the method statement, the calculations, the decisions made, and the results of flood estimation. This document can be used for one site or multiple sites.

Guidance notes to help you complete this template are available separately.

Contents

Approval

Revision stage	Analyst:	Approved by:	Amendments	Date
Method statement	Joseph Bentley (Consultant)	Daniel Hamilton (Principal Consultant)		14/08/2024
Calculations - Revision 1				
Calculations - Revision 2				

Abbreviations

Abbreviation	Short for
AEP	annual exceedance probability
AMAX	Annual Maximum
AREA	Catchment area (km2)
BFI	Base Flow Index
BFIHOST19	Base Flow Index derived using the HOST soil classification, revised in 2019
FARL	FEH index of flood attenuation due to reservoirs and lakes
FEH	Flood Estimation Handbook
GEV	Generalised Extreme Value
GLO	Generalised Logistic
HOST	Hydrology of Soil Types
IF	Impervious Fraction
IRF	Impervious Runoff Factor
LF	Low flow statistics (flow duration curve)
NRFA	National River Flow Archive
POT	Peaks Over a Threshold
QMED	Median Annual Flood (with return period 2 years)
ReFH	Revitalised Flood Hydrograph method
ReFH2	Revitalised Flood Hydrograph 2 method
SAAR	Standard Average Annual Rainfall (mm)
Tp	Time to peak of the instantaneous unit hydrograph
URBAN	Flood Studies Report index of fractional urban extent
URBEXT1990	FEH index of fractional urban extent
URBEXT2000	Revised index of urban extent, measured differently from URBEXT1990
WINFAP	Windows Frequency Analysis Package (software that can be used for FEH statistical method)

1. Summary of assessment

1.1 Summary

Catchment location:

The assessment is for the Little Stainton Beck at NGR: 433800, 521550, near the village of Great Stainton.

Purpose of study and complexity:

Hydrology assessments are required to derive peak flows and hydrographs for four sub-catchments. These will be used as inputs into a hydraulic model to inform flood risk at a proposed solar farm. The complexity of the assessment is considered to be routine.

Key catchment features:

Small (no assessed catchment above 3.5km^2), impermeable and essentially rural.

Flooding mechanisms:

Fluvial

Gauged / ungauged:

Ungauged

Final choice of method:

Rainfall-Runoff

Key limitations / uncertainties in results:

No major uncertainty or limitations with the exception of no insitu gauged data.

1.2 Flood frequencies

- The frequency of a flood can be quoted in terms of a return period, which is defined as the average time between years with at least one larger flood, or as an annual exceedance probability (AEP), which is the inverse of the return period.
- Return periods are output by the Flood Estimation Handbook (FEH) software and can be expressed more succinctly than AEP. However, AEP can be helpful when presenting results to members of the public who may associate the concept of return period with a regular occurrence rather than an average recurrence interval.
- Results tables in this document contain both return period and AEP titles; both rows can be retained, or the relevant row can be retained and the other removed, depending on the requirement of the study.
- The table below is provided to enable quick conversion between return periods and annual exceedance probabilities.

AEP (%)	50	20	10	5	3.33	2	1.33	1	0.5	0.1
AEP	0.5	0.2	0.1	0.05	0.033	0.02	0.013	0.01	0.005	0.001
Return period (yrs)	2	5	10	20	30	50	75	100	200	1,000

2. Method Statement

2.1 Requirements for flood estimates

Overview and Project Scope:

The purpose of the study is to generate hydrographs as input into a 2D-only model. Design estimates will be made for the 3.3%, 1.0%, 0.1% and 1.0% + climate change AEP events. Both the 40% higher central and 61% upper end allowances will be assessed for the 2080s epoch, Tees management catchment[1].

Four separate flow estimates will be produced to derive peak flows and hydrographs for two lateral inflows and two direct inflows. The hydraulic model will be to inform flood risk at a proposed solar farm adjacent to the watercourse. The complexity of the assessment is considered to be routine.

2.2 The Catchment

Maps:

The map below illustrates the overall catchment area for the study as derived by the FEH webservice. The downstream boundary of the catchment is denoted by the orange arrow.

1 EA(2024) Peak river flow allowances, environment.data.gov.uk/hydrology/climate-change-allowances/river-flow).

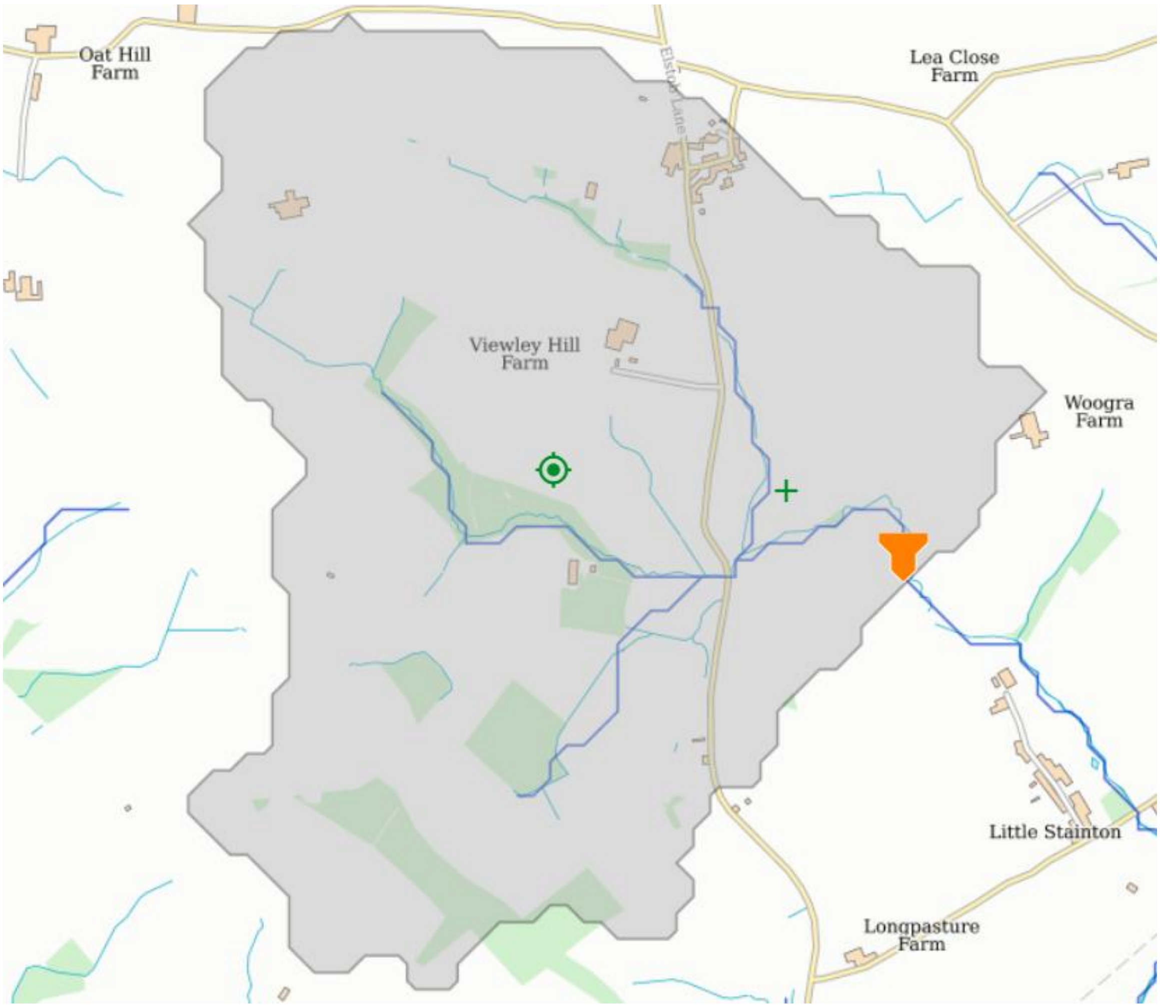


Figure 1- The FEH Web Service derived catchment is shown by the grey boundary. Contains OS data © Crown Copyright (2024) Contains CEH data © and database right NERC (CEH) 2024

Catchment Description:

The area of the boundary is 4.76m^2. The majority of the catchment is underlain by dolostone, with smaller areas of dolomitic limestone and mudstone. Superficial deposits of till, alluvium, lacustrine and glaciofluvial deposits are also in evidence.

Based on the Landis Soilscapes mapping[2], soils present are slowly permeable loamy and clayey soils. The catchment is not affected by the presence of lakes and is therefore assigned a FARL value of 1. The catchment has an URBEXT2000 value of 0.0024 hence is classed as 'essentially rural' according to FEH guidance. Land use is primarily open grassland or agricultural. No unusual land use features are present in the reach.

2 LandIS (2024) Soilscapes Viewer https://www.landis.org.uk/soilscapes/

2.3 Hydrometric Data

Source of flood peak data:

NRFA peak flows dataset, Version 12.1.1, released in October 2023. This contains data up to water year 2022-23.

Gauging stations (flow and level):

The catchment is ungauged

Updates or revisions to flood peak data:

None

Data quality checks carried out:

None

Rating Equations:

None

Station name	Type of rating e.g., theoretical, empirical; degree of extrapolation	Rating review needed?	Comments and link to any rating reviews

Rating reviews:

None

Other data available and how it has been obtained:

Type of data	Data relevant to this study?	Data available?	Source of data	Details
Check flow gaugings	No			
Historical flood data	No			
Flow or river level data for events	No			
Rainfall data for events	No			
Potential evaporation data	No			
Results from previous studies	No			
Other data or information				

Conclusions of hydrometric data review:

Station name	Rating suitability	Suitability for flood estimation calculations	Non-stationary analysis requirements

2.4 Hydrological understanding of the catchment

Plots of flood peak data and interpretation:

N/A

Plots of flow data and interpretation:

N/A

Plots of stage data and interpretation:

N/A

Conceptual model:

The area of interest is approximatley 1km to the south of Great Stainton. Peak flows rather than total flood volumes are considered to be the primary cause of flooding. This is due to the size of catchment and lack of floodplain or lake/reservoir storage. with it being a small channel/catchment with no further dam or reservoir considerations required.

Given the catchment size it is relatievly homegenous with different parts of the catchment likely responding in the same way to in general.

The main sites of interest will include the top of the reach and key tributaries with lateral inflows used to represent intervening areas.

Unusual catchment features:

No unusual catchment characteristics are present.

2.5 Initial choice of approach

Are FEH methods appropriate?

Yes - Standard catchment with no unusual features.

Initial choice of method(s) and reasons:

The flood estimates have been developed using the Flood Estimation Handbook statistical and rainfall runoff methods. The statistical methods are those as published by the Institute of Hydrology in 1999[3] with updates included in the latest version of WINFAP-FEH 5[4] as described by Kjeldsen et al.,[5] and the WHS technical guidance[6]. These methods require the estimation of a normalised flood frequency curve, termed the flood growth curve and the estimation of the normalising variable; the median annual flood, QMED.

3 Robson, A. and Reed, D., 1999. Flood Estimation Handbook Volume 3: Statistical Procedures for Flood Frequency Estimation. Institute of Hydrology, Wallingford, pp338.
4 https://www.hydrosolutions.co.uk/software/winfap-5/

5 Kjeldsen, T.R., Jones, D.A., and Bayliss, A.C., 2008. Improving the FEH statistical procedures for flood frequency estimation. Environment Agency, Bristol, pp137.
6 https://www.hydrosolutions.co.uk/software/winfap-4/literature/

The rainfall-runoff methods are those first published by Kjeldsen[7], which were subsequently updated in 2015 and 2019 and implemented within the ReFH2.3 software[8] as described in the WHS technical guidance[9]. The latest FEH22 rainfall model[10] has been used in the derivation of rainfall inputs for the catchment.

This approach is considered to be appropriate given that the catchment's size and that it has no unusual features.

How will hydrograph shapes be derived if needed?

Hydrographs will be generated using the ReFH (v2.3) model. The hydrographs for each subject site will be generated using the recommended duration estimated at the downstream boundary of the study catchment shown in Figure 1. The recommended duration estimated by the REFH 2.3 software for this catchment is 5.5 hours with a timestep of 0.5 hours.

Will the catchment be split into sub-catchments? If so, how?

The catchment will be split into two direct and two lateral inflows. The two direct estimates will be lumped and will represent the catchment defined at upstream extent of the reach and an incoming tributary (Byers Gill) roughly mid-way down the reach. The two lateral inflows represent the intevening areas between these inflows and the area downstream of their conflunce to the downstream boundary of the study catchment.

Software to be used:

ReFH 2.3

WINFAP 5.1

7 Kjeldsen, T. R. 2007. The revitalised FSR/FEJ rainfall-runoff method. Supplementary Report No.1. CEH.

8 https://www.hydrosolutions.co.uk/software/refh-2/

9 https://www.hydrosolutions.co.uk/software/refh-2/supporting_literature/

10 https://fehwebdocs.hydrosolutions.co.uk/DDF-Science/FEH22/

3. Locations where flood estimates are required

3.1 Summary of subject sites

The map below shows the four inflows, The two direct being DIR1 and DIR2 and the two laterals being LAT1 and LAT2.

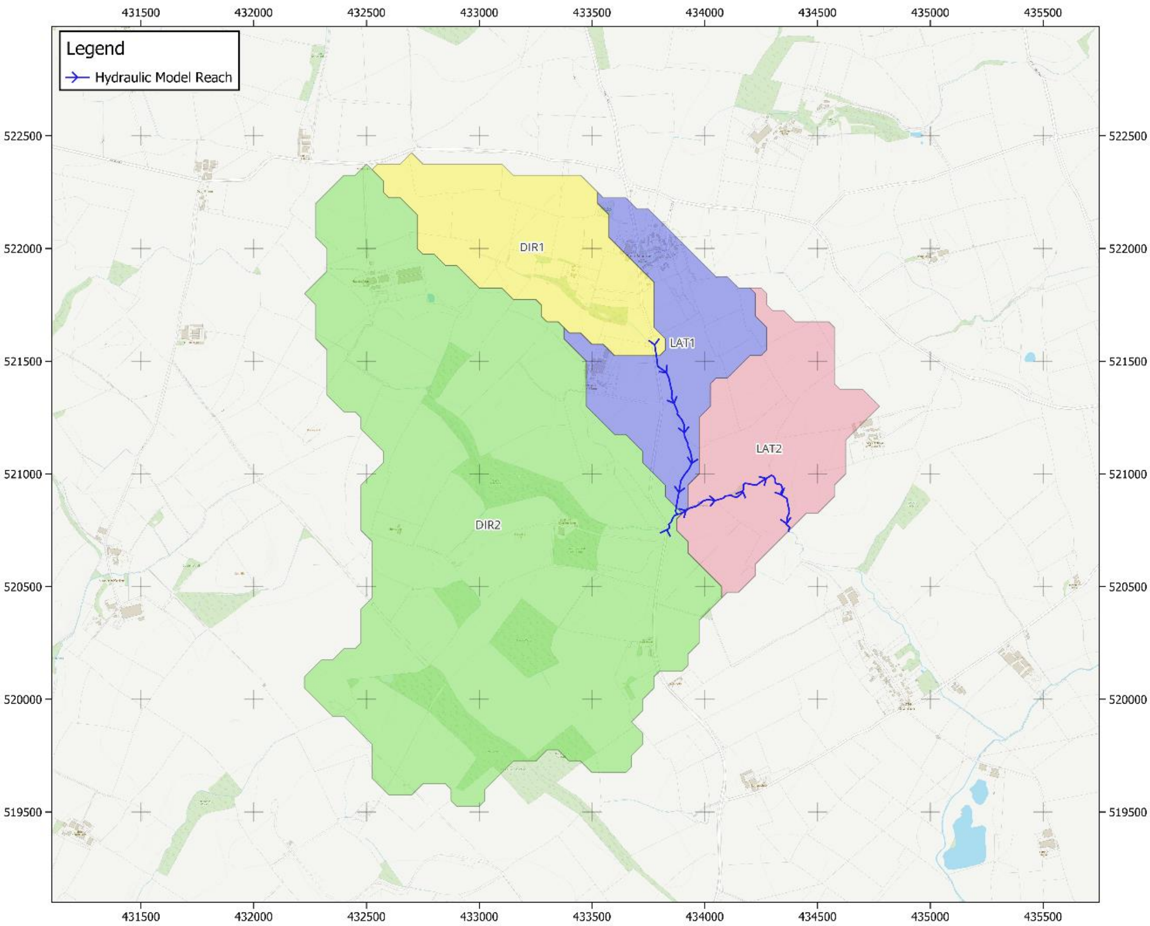


Figure 2- Mapped overview of subject sites catchment

Site code	Type of estimate: lumped (L) or sub-catchment (S)	Water-course	Site name / descrip-tion	Easting	Northin g	AREA on FEH Web Service (km^2)	Revised AREA (if altered) (km^2)
DIR1	L	Little Stainton Beck	Little Stainton Beck	433800	521550	0.59	N/A
DIR2	L	Byers Gill	Byers Gill	433850	520750	2.61	3.03*
LAT1	S	Little Stainton Beck	Intervening area between DIR1 and DIR2	433900	520850	Estimated as 0.5125	
LAT2	S	Little Stainton Beck	Intervening area between DIR2 and ds extent of the study catchment	434350	520750	Estimated as 0.6150	

*See section 3.2 for explanation

3.2 Catchment Descriptors

Final catchment descriptors at each subject site:

Site code	FARL	PROPWET	BFIHOST19	DPLBAR (km)	DPSBAR (m/km)	SAAR (mm)	URBEXT 1990	URBEXT 2000	FPEXT
DIR1	1	0.32	0.376	0.87	41	619	0.0168	0.0105	0.0294
DIR2	1	0.32	0.382	1.38	34.3	616	0	0	0.0919
LAT1	1	0.32	**0.3717**			**614.68**		**0.0097**	**0.1024**
LAT2	1	0.32	**0.3413**			**609.26**		**0.0004**	**0.0758**

Catchment boundary checks and revisions:

When defining the Byers Gill catchment (DIR2), the FEH web service appears to miss the catchment for a small tributary inflow immediately upstream of the confluence between Byers Gill and the Little Stainton Beck. To account for this the Byers Gill catchment (DIR2) was expanded. This approach was deemed acceptable as based on available mapping the tributary catchment clearly drains to the Byers Gill catchment. Figure 3 shows an overview of the catchment areas before the amendment was made. The infilled area is approximately 0.5km^2, with similar land use and geology to the original catchment.

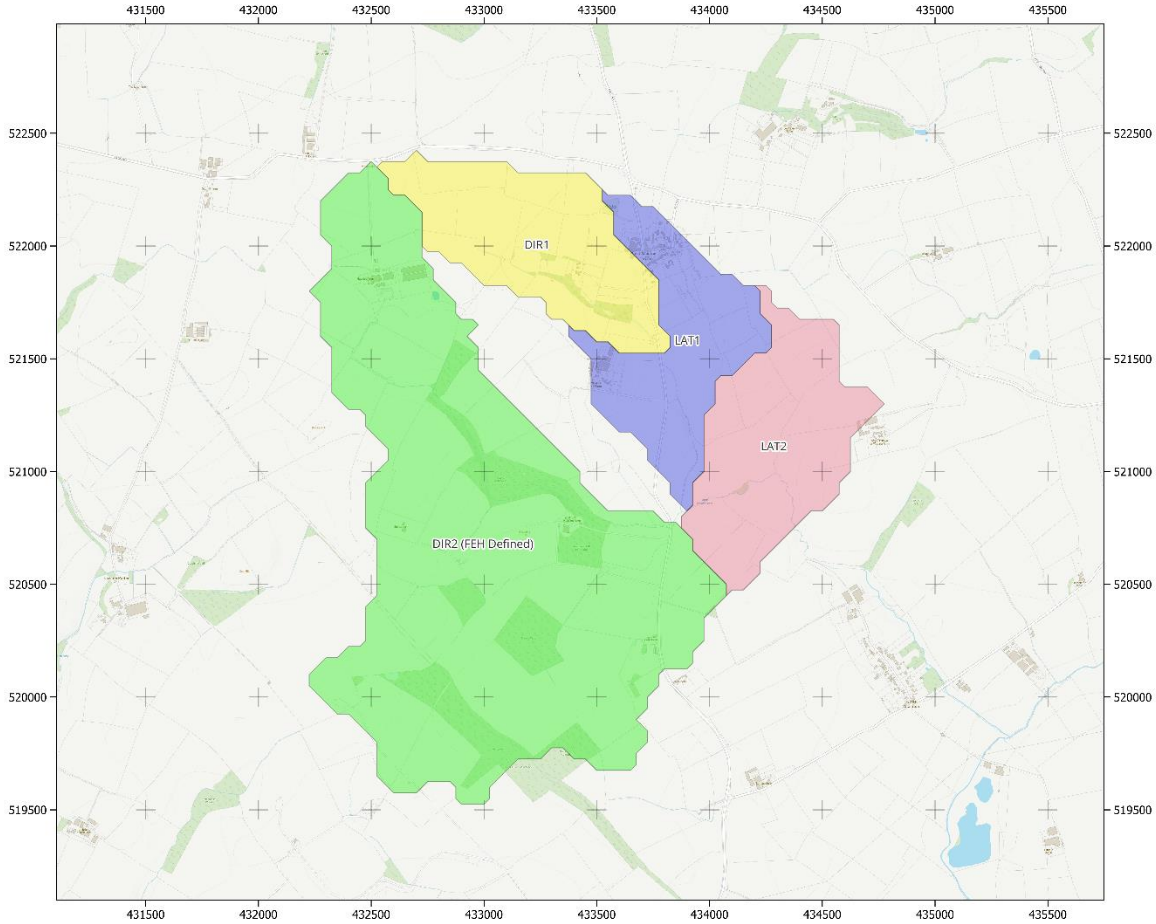


Figure 3- Mapped overview of subject sites catchment from FEH Web Service

URBEXT source and method for updating:

URBEXT2000

BFIHOST source, checks and updates:

BFIHOST19 used, all BFIHOST19 values are between 0.341 and 0.382. Slowly permeable, seasonally wet slightly acid but base rich loamy and clayey soils are present throughout all catchments indicating low BFIHOST19, which is reflected in the BFIHOST19 values.

Checks and revisions to other catchment descriptors:

The descriptors for the 2 lateral inflows were derived using an area weighted averaging approach where appropriate (e.g. BFIHOST19, SAAR and PROPWET) and also by taking into account upstream areas (e.g. FARL and URBEXT2000). Plot scale equations were also applied to all lateral inflows. This avoided recalculation of DPLBAR and DPSBAR which can be subject to uncertainty. Across small catchments (area less than 40 km^2) the estimates generated using the plot scale and catchment scale equations are broadly similar, therefore their application is considered to be appropriate.

4. Stationary statistical methods

4.1 Method overview

What is the purpose of applying these methods?

The statistical method is used to derive peak flows for each subject site. These peak flows will be compared to those derived using the ReFH2 method. If the statistical are higher and/or are considered more appropriate to use, the ReFH2 hydrographs will be scaled to them and used as input into the hydraulic model.

What methods will be used to estimate QMED and growth curves?

Site code	Methods used for QMED	Methods used for growth curves
DIR1	Donor Adjusted	Pooled analysis
DIR2	Donor Adjusted	Pooled analysis
LAT1	Donor Adjusted	Pooled analysis
LAT2	Donor Adjusted	Pooled analysis

4.2 Estimating QMED

QMED at gauged subject sites:

No gauged sites present.

Site code	Method (AM/ POT/LF)	Initial QMED (m^3/s)	Number of water years of data used	Adjustment for climatic variation?	Final QMED (m^3/s)

Methods: AM – Annual maxima; POT – Peaks over threshold; LF – Low flow (flow duration curve) statistics.

QMED at ungauged subject sites:

Site code	Method (CD/ DT/BCW)	Initial QMED (rural) from CDs (m^3/s)	Donors used (NRFA numbers)	Donor distances from subject centroid (km)	Individual donor weights	Combined and weighted donor adjustment factor	Urban adjustment factor	Final QMED (m^3/s)
DIR1	DT	0.168	27094, 25005, 25029, 24007	22.00, 24.61, 25.05, 31.25	Unknown	0.893	1.00992	0.152
DIR2	DT	0.651	27094, 25005, 25029, 24007	20.76, 24.05, 24.51, 32.04	Unknown	0.896	1.00000	0.583
LAT1	DT	0.145	27094, 25005, 25029, 24007	21.74, 24.25, 24.70, 31.60	Unknown	0.903	1.00910	0.132
LAT2	DT	0.177	27094, 25005, 25029	21.08, 24.11, 24.56	Unknown	0.927	1.00036	0.164

Methods: CD - Catchment descriptors alone; DT - catchment descriptors with donor transfer; BCW - catchment descriptors with bankfull channel width.

Urban adjustment of QMED:

WINFAP 5, IF: 0.3, PRimp: 70%, URBAN: URBEXT 2000

Search for donor sites:

In general, donor sites were selected if the donor catchment had a SAAR of within 30% of the FEH descriptors, a BFIHOST19 of within 20%, and FARL within 0.075.

Donor sites chosen and QMED adjustment factors:

NRFA no.	Method (AM/ POT/LF)	Adjustment for climatic variation?	QMED from flow data (m^3/s)	De-urbanised QMED from flow data (m^3/s) (A)	QMED from catchment descriptors (m^3/s) (B)	Adjustment ratio (A/B)
27094	AM	No	13.525	13.295	20.875	0.637
25005	AM	No	43.320	42.772	35.880	1.192
25029	AM	No	37.387	36.904	34.987	1.055
24007	AM	No	10.981	10.972	13.680	0.802

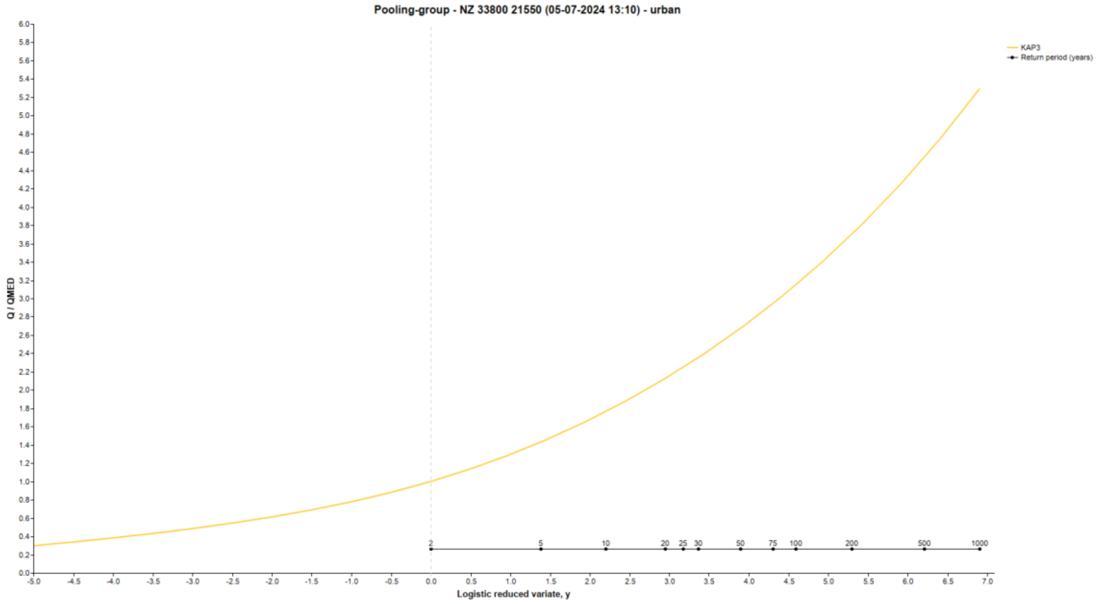
Methods: AM – Annual maxima; POT – Peaks over threshold; LF – Low flow (flow duration curve) statistics.

4.3 Estimating growth curves

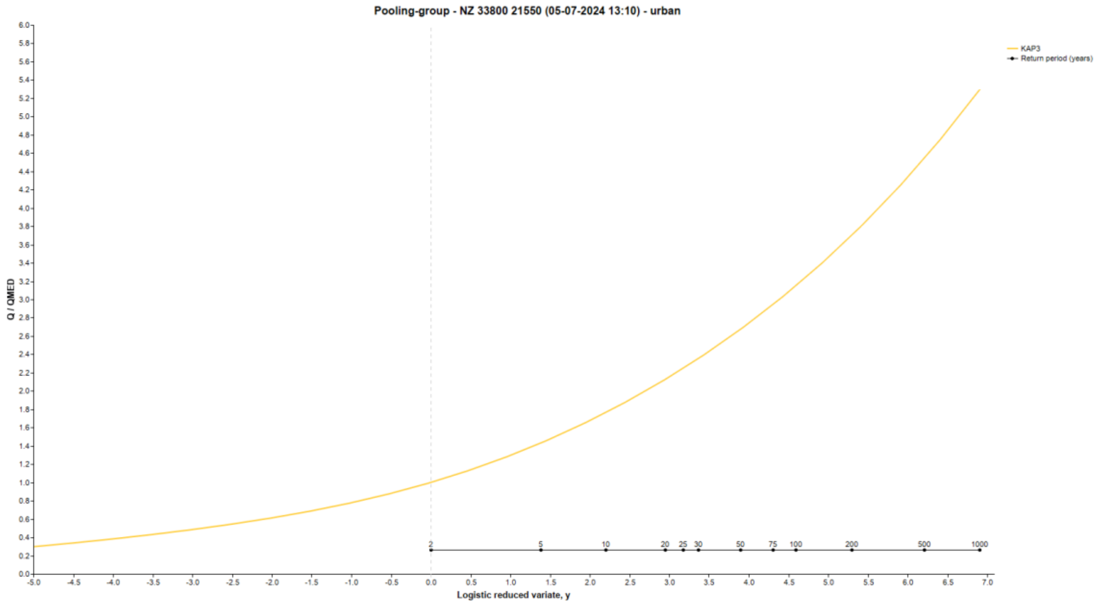
Derivation of growth curves at subject sites:

The pooling group and growth curve for DIR1 was adopted for LAT1 and LAT2. This was due to i). the catchments being adjacent to one another, ii). having similar catchment areas (approximately 0.5km^2), iii). being located on similar geologies (BFIHOST19 between 0.341 and 0.376) and iv). having similar rainfall charcteristics (SAAR between 619 and 609). The KAPPA distribution showed the best fit to the growth curve and was applied. There are two stations (36010, 44008) with more than 15% non-flood years in the pooling group, non-flood year adjustment was applied to the GL distribution to assess their impact, however as it was minimal, the KAPPA distribution was retained.

A separate pooling group and growth curve was derived for DIR2. A separate pooling group was derived because the DIR2 catchment was significantly larger than the other catchments (approx. 3km^2). DIR2 also represented a separate watercourse (Byers Gill) to the other three estimations (Little Stainton Beck).



DIR1 growth curve (KAPPA)



DIR2 derived growth curve (KAPPA)

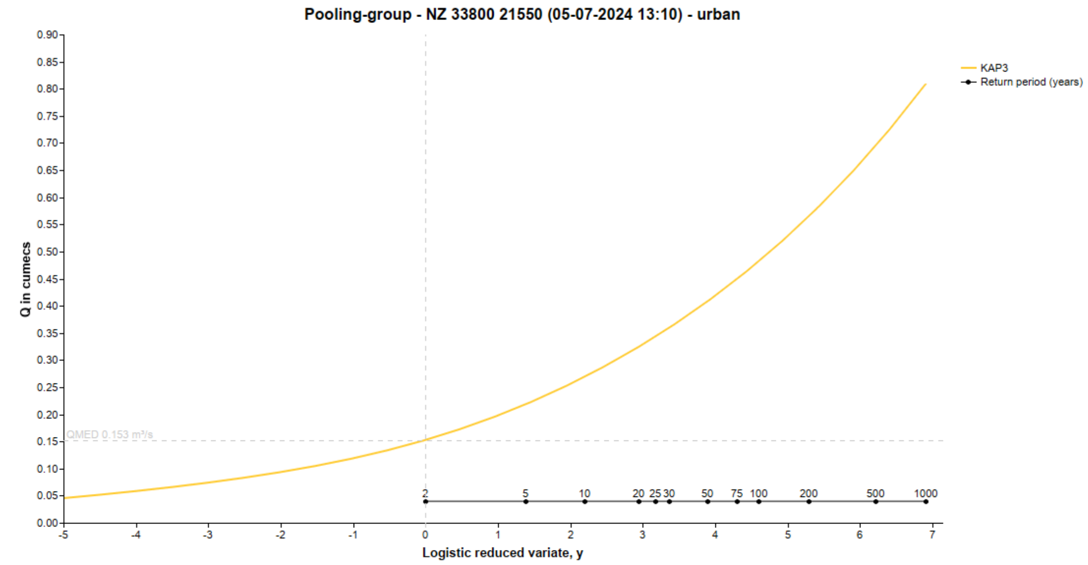
Site code	Method (SS, P, ESS, H.)	If P or ESS, name of pooling group	Distribution used and reason for choice	Any urban or non-flood years adjustments	Parameters of distribution (location, scale and shape after adjustments)	Growth factor for 100-year return period
DIR1	P	DIR1	KAPPA - Provided the best fit	Non-flood year adjustment applied	See Above image for distribution differences	3.152
DIR2	P	DIR2	KAPPA - Provided the best fit	Non-flood year adjustment applied	See Above image for distribution differences	3.046
LAT1	P	DIR1	KAPPA - Provided the best fit	Non-flood year adjustment applied	See Above image for distribution differences	3.152
LAT2	P	DIR1	KAPPA - Provided the best fit	Non-flood year adjustment applied	See Above image for distribution differences	3.155*

Methods: SS - Single Site; P - Pooled; ESS - Enhanced Single Site; H - Historical. Pooled and ESS growth curves were derived using the procedures from Science Report SC050050 (2008). Urban adjustments are carried out using the method of Kjeldsen (2010).

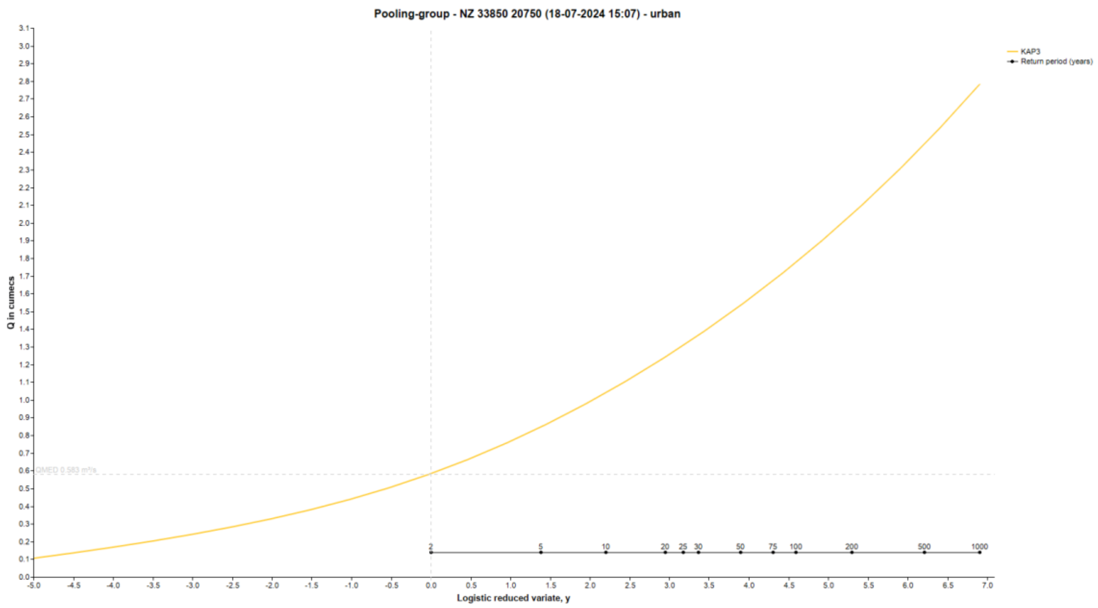
*LAT2 growth factor differs from DIR1 and DIR2 due to urban adjustment of rural growth curve and UAF differences between the three subject sites.

Flood frequency curve plots:

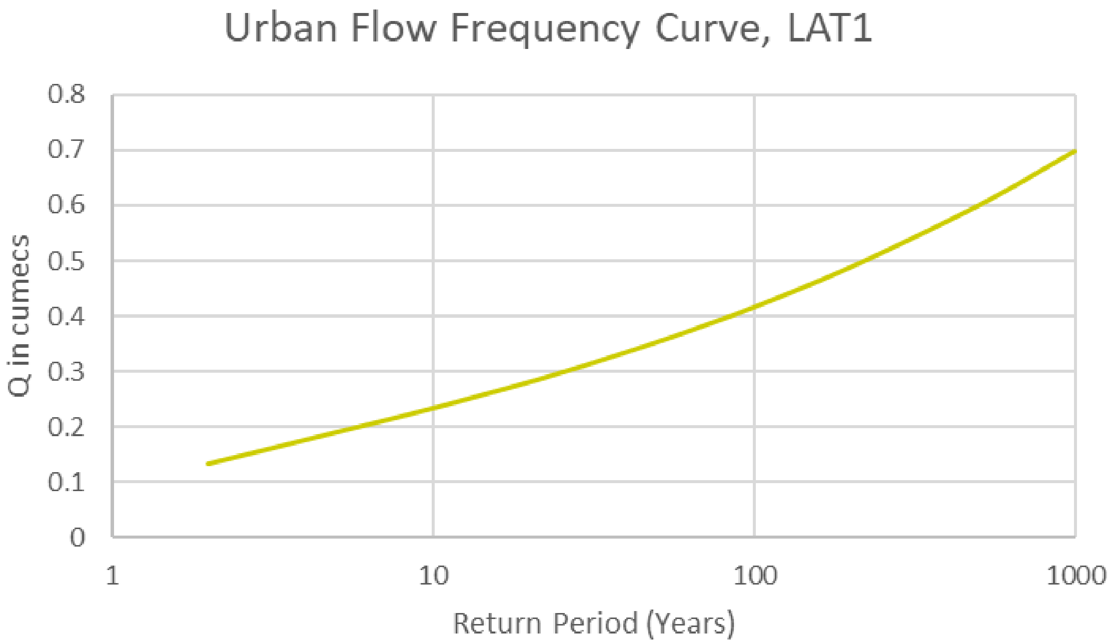
DIR1:



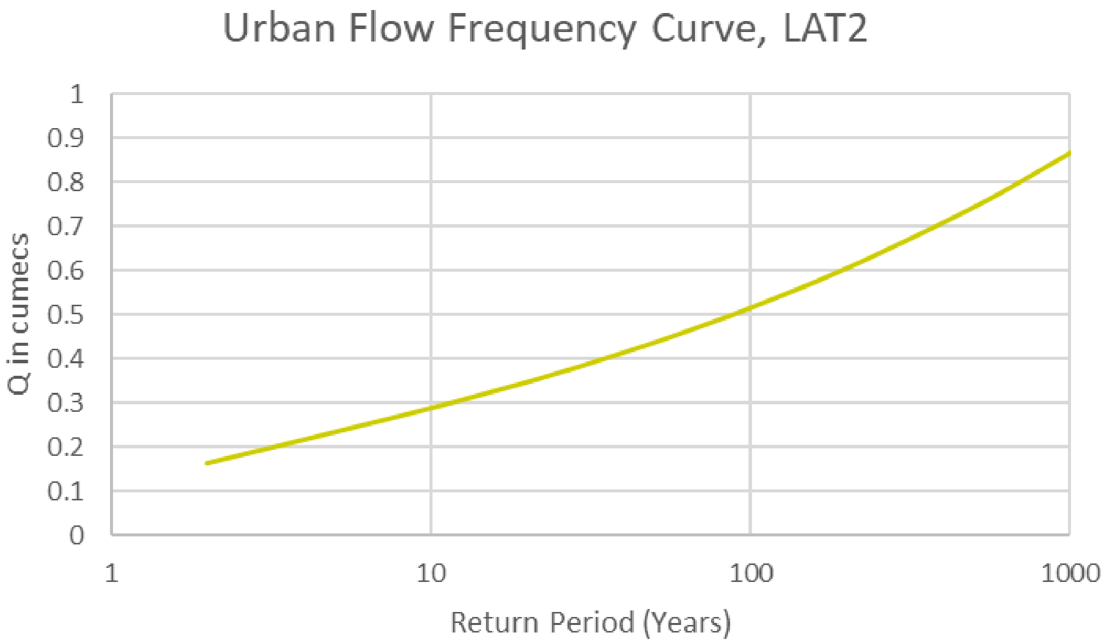
DIR2:



LAT1:


Urban Flow Frequency Curve, LAT1
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Q in cumecs
1
10
100
1000
Return Period (Years)

LAT2:


Urban Flow Frequency Curve, LAT2
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Q in cumecs
1
10
100
1000
Return Period (Years)

Derivation of pooling groups:

Name of group	Site code from whose descriptors group was derived	Subject site treated as gauged? (ESS)	URBEXT2000 threshold applied to pooling group selection?	L-moments deurbanised (including subject site for ESS)?	Small catchment pooling procedure applied?
DIR1*	DIR1	No	0.03	Yes	Yes
DIR2	DIR2	No	0.03	Yes	Yes

Methods: Unless otherwise stated, pooling groups were derived using the procedures from Science Report SC050050 (2008). The small catchment pooling procedure is given in the report on Phase 2 of project SC090031 (2021) and implemented in WINFAP v5.

*DIR1 pooling group and growth curve applied to LAT1 and LAT2

Pooling group composition:

Name of group	Changes made to default pooling group, with reasons	Weighted average L-moments
DIR1	Stations 27073, 26016, 44008, 26014, 39033, 44013 and 33054 rejected due to them being permeable, non-responsive catchments. Station 7011 rejected for high discordancy and no high return period flood events. Station 28058 rejected for having a negative L-Skew value. Stations 47022, 25011, 24007 and 36004 substituted into the pooling group to make up the required 500 total flood years.	L-moments L-CV: 0.251 L-Skew: 0.254
DIR2	Stations 27073, 26016, 26014, 44008, 39033, 33054 and 26103 rejected due to them being permeable, non-responsive catchments. Station 7011 rejected for high discordancy and no high return period flood events. Station 26013 rejected for having a negative L-Skew value. Stations 36004, 24007, 53017, 9006 and 36003 substituted into the pooling group to make up the required 500 total flood years.	L-moments L-CV: 0.264 L-Skew: 0.211

4.4 Final choice of QMED and growth curves

Method choice and reasons:

Site code	Final choice of QMED and reasons	Final choice of flood growth curve method and reasons
DIR1	Donor Transfer. Accounts for potential local bias in QMED CDS equation.	Pooled analysis. Recommended method for ungauged catchments.
DIR2	Donor Transfer. Accounts for potential local bias in QMED CDS equation.	Pooled analysis. Recommended method for ungauged catchments.
LAT1	Donor Transfer. Accounts for potential local bias in QMED CDS equation.	Pooled analysis. Considered appropriate to use DIR1 growth curve for reasons discussed.
LAT2	Donor Transfer. Accounts for potential local bias in QMED CDS equation.	Pooled analysis. Considered appropriate to use DIR1 growth curve for reasons discussed.

Final flood estimates from stationary statistical methods:

Site code	2 50%	5 20%	10 10%	20 5%	30 3.3%	50 2%	75 1.3%	100 1%	200 0.5%	1000 0.1%
DIR1	0.152	0.218	0.268	0.323	0.358	0.406	0.448	0.479	0.562	0.805
DIR2	0.583	0.847	1.038	1.240	1.365	1.532	1.671	1.776	2.045	2.781
LAT1	0.132	0.189	0.233	0.280	0.311	0.353	0.389	0.416	0.488	0.699
LAT2	0.164	0.235	0.289	0.348	0.386	0.438	0.483	0.517	0.607	0.869

Flood peak in m^3/s for the return periods in years or AEP (%) events.

5. Non-stationary statistical methods

5.1 Method Overview

What is the purpose of applying these methods?

What methods will be used?

Site code	If ungauged, which gauging station is being used?	Methods used to test for trends and change points	Methods used for non-stationary frequency analysis

5.2 Testing for trends and change points

Non-parametric trend tests:

Step change tests:

Split sample tests:

Interpretation and conclusions:

5.3 Non-stationary frequency analysis

Selection of covariates:

Fitting non-stationary models:

Interpretation and conclusions:

Final flood estimates from non-stationary statistical methods:

Site code	2 50%	5 20%	10 10%	20 5%	30 3.3%	50 2%	75 1.3%	100 1%	200 0.5%	1000 0.1%

Flood peak in m^3/s for the return periods in years or AEP (%) events.

6. Revitalised flood hydrograph (ReFH1) method

6.1 Method Overview

What is the purpose of applying this method?

Rural and urban catchment sub-divisions:

6.2 Model Parameters

Summary of model parameters:

Site code	Method	Tp (hours) rural	Tp (hours) urban	Cmax (mm)	BL (hours)	BR	PR_{imp} %

Methods: OPT: Optimisation from event analysis, BR: Baseflow recession fitting, LAG: TP from lag analysis, CD: Catchment descriptors, DT: Data transfer, CAL: model calibration.

Analysis undertaken to derive model parameters:

6.3 Model inputs for design events

Design events for lumped catchments:

Site code	Rainfall DDF model	Urban or rural	Season of design event	Storm duration (hrs)	Initial soil moisture Cini	Initial baseflow BFO

Design events for subcatchments and intervening areas:

Site code(s)	Rainfall DDF model	Season of design event	Storm duration (hrs)	Storm area for ARF	Areal reduction factor (ARF)	Reason for selecting storm

Storm duration testing:

6.4 Final choice of ReFH1 flow estimates

Method choice and reasons:

Site code	Final choice of design inputs and model parameters

Final flood estimates from ReFH1 method:

Site code	2 50%	5 20%	10 10%	20 5%	30 3.3%	50 2%	75 1.3%	100 1%	200 0.5%	1000 0.1%

Flood peak in m^3/s for the return periods in years or AEP (%) events.

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7. Revitalised flood hydrograph 2 (ReFH2) method

7.1 Method Overview

What is the purpose of applying this method?

Generating hydrographs (2 direct and 2 lateral) for use as an input into a 2D-only hydraulic model. These will be compared to the WINFAP peak flow estimates and the most appropriate peak flows will be selected as the eventual input to the model. To provide consistency and ensure a worst case scenario for the site is used as an input to the model, the recommended storm duration for the point furthest downstream has been applied to all REFH estimates.

Version of ReFH2 applied:

ReFH2.3 - FEH22

7.2 Model Parameters

Summary of model parameters:

Plot scale equations were used for both lateral catchments.

Site code	Method	Tp (hours) rural	Cmax (mm)	BL (hours)	Area modelled as urban (km2)	TP urban scaling factor	IF	IRF	DS
DIR1	CD	1.994	299.792	27.984	0.0098	0.75	0.4	0.7	0.5
DIR2	CD	2.748	304.501	31.245	0.0000	0.75	0.4	0.7	0.5
LAT1	CD	2.19	296.462	33.426	0.0078	0.75	0.4	0.7	0.5
LAT2	CD	2.315	273.952	32.104	0.0004	0.75	0.4	0.7	0.5

Methods: OPT: Optimisation from event analysis, BR: Baseflow recession fitting, LAG: TP from lag analysis, CD: Catchment descriptors, DT: Data transfer, CAL: model calibration.

Analysis undertaken to derive model parameters:

7.3 Model inputs for design events

Design events for lumped catchments:

Site code	Rainfall DDF model	Urban or rural	Highly permeable?	Season of design event	Storm duration (hrs)	Initial soil moisture Cini	Initial baseflow BFO
DIR1	FEH22	Urban	No	Winter	5.5 hours	Default value	Default value
DIR2	FEH22	Urban	No	Winter	5.5 hours	Default value	Default value

Design events for subcatchments and intervening areas:

Site code(s)	Rainfall DDF model	Season of design event	Storm duration (hrs)	Storm area for ARF	Areal reduction factor ARF	Reason for selecting storm
LAT1	FEH22	Urban	No	Winter	5.5 hours	Default value
LAT2	FEH22	Urban	No	Winter	5.5 hours	Default value

Storm duration testing:

N/A

7.4 Final choice of ReFH2 flow estimates

Method choice and reasons:

Site code	Final choice of design inputs and model parameters
DIR1	Model parameters from catchment descriptors. Recommended storm duration of 5.5 hours for all inflows.
DIR2	Model parameters from catchment descriptors. Recommended storm duration of 5.5 hours for all inflows.
LAT1	Model parameters from catchment descriptors. Recommended storm duration of 5.5 hours for all inflows.
LAT2	Model parameters from catchment descriptors. Recommended storm duration of 5.5 hours for all inflows.

Final flood estimates from ReFH2 method:

Site code	2 50%	5 20%	10 10%	20 5%	30 3.3%	50 2%	75 1.3%	100 1%	200 0.5%	1000 0.1%
DIR1	0.272	0.380	0.457	0.536	0.584	0.648	0.702	0.742	0.848	1.151
DIR2	1.104	1.536	1.846	2.165	2.361	2.619	2.834	2.994	3.411	4.623
LAT1	0.194	0.313	0.376	0.442	0.482	0.535	0.580	0.613	0.699	0.951
LAT2	0.290	0.403	0.486	0.570	0.621	0.690	0.747	0.789	0.899	1.219

Flood peak in m^3/s for the return periods in years or AEP (%) events.

8. Other Rainfall-Runoff or Hydrograph Methods

8.1 Averaged Hydrograph Shapes

8.2 FSR-FEH Rainfall-Runoff Method

8.3 Direct Rainfall Modelling

9. Discussion and summary of results

9.1 Comparison of results from different methods

Site code	*Ratio of ReFH2 peak to statonary statistical peak, 1% AEP*	*Ratio of ReFH2 peak to statonary statistical peak, 0.1% AEP*
DIR1	1.549	1.430
DIR2	1.686	1.662
LAT1	1.474	1.361
LAT2	1.526	1.403

9.2 Final choice of method

Choice of method and reasons:

The study is to assess the flood risk and inundation to a proposed solar development. ReFH2.3 flows are higher and are therefore used to provide a conservative estimate of flood risk.

How will the 0.1% AEP flows be estimated?

Using ReFH2.3 outputs

How will the flows be applied to a hydraulic model?

Both direct flows will be placed at the point of assessment within the river channel. Both laterals flow will be input across the channel using an SA boundary which will distribute flows accordingly.

9.3 Final results

Site code	2 50%	5 20%	10 10%	20 5%	30 3.3%	50 2%	75 1.3%	100 1%	200 0.5%	1000 0.1%
DIR1	0.272	0.380	0.457	0.536	0.584	0.648	0.702	0.742	0.848	1.151
DIR2	1.104	1.536	1.846	2.165	2.361	2.619	2.834	2.994	3.411	4.623
LAT1	0.224	0.313	0.376	0.442	0.482	0.535	0.580	0.613	0.699	0.951
LAT2	0.290	0.403	0.486	0.570	0.621	0.690	0.747	0.789	0.899	1.219

Flood peak in m^3/s for the return periods in years or AEP (%) events.

Design storms applied in the hydraulic model:

Site code(s)	Season of design event	Storm duration (hrs)	Storm area for ARF (km2)	Return period(s)	Reason for selecting storm
DIR1	Winter	5.5		100-year + CC	Relevant for design and planning regulations.
DIR2	Winter	5.5		100-year + CC	See above
LAT1	Winter	5.5		100-year + CC	See above
LAT2	Winter	5.5		100-year + CC	See above

Climate change allowances:

Both Higher Central and Upper end estimates will be assessed as part of the analysis. These are 40% and 61% respectively. These values can be found on the DEFRA website at: environment.data.gov.uk/hydrology/climate-change-allowances/river-flow

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9.4 Checks

Growth factor checks:

Site code	1% AEP growth factor	0.1% AEP / 1% AEP ratio
DIR1	2.728	1.551
DIR2	2.712	1.544
LAT1	2.737	1.551
LAT2	2.721	1.545

Specific discharge:

Site code	2 50%	5 20%	10 10%	20 5%	30 3.3%	50 2%	75 1.3%	100 1%	200 0.5%	1000 0.1%
DIR1	4.610	6.441	7.746	9.085	9.898	10.983	11.898	12.576	14.373	19.508
DIR2	3.644	5.069	6.092	7.145	7.792	8.644	9.353	9.881	11.257	15.257
LAT1	4.371	6.107	7.337	8.624	9.405	10.439	11.317	11.961	13.639	18.556
LAT2	4.715	6.553	7.902	9.268	10.098	11.220	12.146	12.829	14.618	19.821

Flood peak in l/s/ha for the return periods in years or AEP (%) events.

Spatial consistency of results:

The hydrographs derived should result in a consistent increase in flow moving downstream. This will be confirmed following a review of the model results.

An identical storm duration has been used for all catchments pertaining to the recommended duration at the downstream boundary. This approach should help safeguard spatial consistency.

Return periods for notable historic floods:

No available notable historic floods recorded for the reach.

Compatibility with longer-term flood history:

No historic flood data available.

Comparisons with previous studies:

No previous studies available

Checks on hydraulic model results:

These estimates will be used to inform a hydraulic model. As of yet no checks have been undertaken, however the modelling results will be reviewed to ensure they are within reasonable bounds.

9.5 Assumptions, limitations, and uncertainty

Assumptions (specific to this study):

- The DIR1 pooling group sufficiently represents both LAT1 and LAT2.
- The decision to not apply non-flood year adjustment and apply the best fitting KAPPA provides a more representative growth curve.
- Topographical catchments are assumed to be correct

Limitations:

- FEH methods may not represent the very localised high intensity rainstorms potentially present at this location.
- No observed gauge data is available for the reach to verify the flows estimated.

Uncertainty:

It is difficult to quantify uncertainty in design flows estimated from the ReFH rainfall-runoff model. One approach, which has not yet been achieved, would be to combine the uncertainty in the rainfall frequency statistics with the uncertainty due to the estimation of rainfall-runoff model parameters and that due to the composition of the design event package.

For now, the factorial standard errors associated with the statistical method when applying one donor site to an ungauged site have been used. The factorial standard errors from ReFH2 are generally expected to be comparable to these.

Site code	50% AEP Lower 95%	50% AEP Upper 95%	5% AEP Lower 95%	5% AEP Upper 95%	1% AEP Lower 95%	1% AEP Upper 95%	0.1% AEP Lower 95%	0.1% AEP Upper 95%
DIR1	0.136	0.549	0.257	0.787	0.349	1.573	0.518	2.567
DIR2	0.552	2.230	1.039	3.180	1.407	6.347	2.080	10.309
LAT1	0.112	0.452	0.212	0.648	0.288	1.300	0.428	2.121
LAT2	0.145	0.586	0.274	0.834	0.371	1.673	0.549	2.718

Upper and lower 95% confidence bounds for the flood peak in m^3/s for the AEP (%) events.

Suitability of results for future studies:

Suitable, the hydrology has been produced based on best practice guidance and where there are assumptions they are deemed sensible.

Recommendations for future work:

Flow monitoring and the development of rating curves may help improve flow estimates at this location.

10. Appendix

10.1 Digital files

Input data:

Project or calculation files:

Output data:

10.2 Other Supporting Information

DIR1 Pooling Group:

Growth curve data and results

Pooling group AM data

Station	Distance	Years of data	QMED AM	L-CV Observed	L-CV Deurbanised	L-SKEW Observed	L-SKEW Deurbanised
76011 (Coal Burn @ Coalburn)	1.821	45	1.840	0.171	**0.171**	0.292	**0.292**
27051 (Crimple @ Burn Bridge)	2.270	50	4.641	0.218	**0.218**	0.133	**0.133**
25019 (Leven @ Easby)	2.692	44	5.384	0.340	**0.341**	0.367	**0.366**
45816 (Haddeo @ Upton)	2.721	29	3.248	0.289	**0.290**	0.432	**0.431**
49005 (Bolingey Stream @ Bolingey Cocks Bridge)	3.008	12	4.924	0.266	**0.267**	0.268	**0.267**
28033 (Dove @ Hollinsclough)	3.024	47	4.150	0.231	**0.231**	0.381	**0.381**
36010 (Bumpstead Brook @ Broad Green)	3.038	55	7.590	0.352	**0.354**	0.109	**0.108**
27010 (Hodge Beck @ Bransdale Weir)	3.042	41	9.420	0.224	**0.224**	0.293	**0.293**
41020 (Bevern Stream @ Clappers Bridge)	3.394	53	13.660	0.201	**0.202**	0.172	**0.170**
47022 (Tory Brook @ Newnham Park)	3.403	27	6.176	0.246	**0.248**	0.151	**0.149**
25011 (Langdon Beck @ Langdon)	3.459	36	15.878	0.223	**0.223**	0.321	**0.320**
24007 (Browney @ Lanchester)	3.492	15	10.981	0.222	**0.222**	0.212	**0.211**
36004 (Chad Brook @ Long Melford)	3.514	55	4.807	0.301	**0.302**	0.176	**0.175**
Total		**509**					

Pooling Group Rejected Stations

Station	Distance	Years of data	QMED AM	L-CV Observed	L-CV Deurbanised	L-SKEW Observed	L-SKEW Deurbanised
27073 (Brompton Beck @ Snainton Ings)	2.108	42	0.816	0.212	0.213	0.020	0.018
26016 (Gypsey Race @ Kirby Grindalythe)	2.660	25	0.101	0.309	0.309	0.249	0.249
44008 (South Winterbourne @ Winterbourne Steepleton)	3.124	31	0.544	0.413	0.414	0.268	0.267
26014 (Water Forlornes @ Driffield)	3.193	24	0.431	0.318	0.319	0.185	0.184
7011 (Black Burn @ Pluscarden Abbey)	3.342	10	4.752	0.494	0.494	0.554	0.553
39033 (Winterbourne Stream @ Bagnor)	3.454	60	0.401	0.340	0.340	0.376	0.376
28058 (Henmore Brook @ Ashbourne)	3.464	13	10.600	0.145	0.147	-0.046	-0.049
44013 (Piddle @ Little Puddle)	3.487	30	0.895	0.488	0.489	0.276	0.275
33054 (Babingley @ Castle Rising)	3.495	46	1.132	0.229	0.229	0.189	0.188

DIR2 Pooling Group:

Growth curve data and results

Pooling group AM data

Station	Distance	Years of data	QMED AM	L-CV Observed	L-CV Deurbanised	L-SKEW Observed	L-SKEW Deurbanised
27051 (Crimple @ Burn Bridge)	1.223	50	4.641	0.218	**0.218**	0.133	**0.133**
25019 (Leven @ Easby)	1.530	44	5.384	0.340	**0.341**	0.367	**0.366**
76011 (Coal Burn @ Coalburn)	1.723	45	1.840	0.171	**0.171**	0.292	**0.292**
36010 (Bumpstead Brook @ Broad Green)	1.750	55	7.590	0.352	**0.354**	0.109	**0.108**
27010 (Hodge Beck @ Bransdale Weir)	1.977	41	9.420	0.224	**0.224**	0.293	**0.293**
49005 (Bolingey Stream @ Bolingey Cocks Bridge)	2.006	12	4.924	0.266	**0.267**	0.268	**0.267**
45816 (Haddeo @ Upton)	2.037	29	3.248	0.289	**0.290**	0.432	**0.431**
41020 (Bevern Stream @ Clappers Bridge)	2.207	53	13.660	0.201	**0.202**	0.172	**0.170**
36004 (Chad Brook @ Long Melford)	2.226	55	4.807	0.301	**0.302**	0.176	**0.175**
24007 (Browney @ Lanchester)	2.252	15	10.981	0.222	**0.222**	0.212	**0.211**
53017 (Boyd @ Bitton)	2.311	49	13.870	0.241	**0.244**	0.090	**0.088**
9006 (Deskford Burn @ Cullen)	2.323	12	19.727	0.291	**0.291**	0.186	**0.186**
36003 (Box @ Polstead)	2.329	62	3.875	0.308	**0.311**	0.084	**0.082**
Total		**522**					

Pooling Group Rejected Stations

Station	Distance	Years of data	QMED AM	L-CV Observed	L-CV Deurbanised	L-SKEW Observed	L-SKEW Deurbanised
27073 (Brompton Beck @ Snainton Ings)	0.895	42	0.816	0.212	0.213	0.020	0.018
26016 (Gypsey Race @ Kirby Grindalythe)	1.435	25	0.101	0.309	0.309	0.249	0.249
26014 (Water Forlornes @ Driffield)	1.927	24	0.431	0.318	0.319	0.185	0.184
44008 (South Winterbourne @ Winterbourne Steepleton)	2.067	31	0.544	0.413	0.414	0.268	0.267
7011 (Black Burn @ Pluscarden Abbey)	2.113	10	4.752	0.494	0.494	0.554	0.553
39033 (Winterbourne Stream @ Bagnor)	2.183	60	0.401	0.340	0.340	0.376	0.376
33054 (Babingley @ Castle Rising)	2.215	46	1.132	0.229	0.229	0.189	0.188
28058 (Henmore Brook @ Ashbourne)	2.278	13	10.600	0.145	0.147	-0.046	-0.049
26013 (Driffield Trout Stream @ Driffield)	2.291	12	2.778	0.274	0.275	0.237	0.236